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U.S. DEPARTMENT OF AGRICULTURE

AGRICULTURAL RESEARCH SERVICE

2005 PROGRESS REPORT

"RESEARCH RESULTS IN PLAIN LANGUAGE" FROM THE

GRAIN MARKETING AND PRODUCTION RESEARCH CENTER

1515 College Avenue
Manhattan, Kansas 66502

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The Cover for Progress Report 2005: Each year the Center holds a contest to select the photograph that is used for the front cover. This year's winning selection was submitted by Mr. Dennis Tilley, Technician in our Engineering Research Unit. The picture was taken by Mr. David Mayes.

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WELCOME TO GMPRC

Since its establishment in 1970, the Agricultural Research Service=s Grain Marketing and Production Research Center (GMPRC) has been the U.S. Department of Agriculture=s main location for conducting research on measuring and controlling the quality of cereal grains throughout the grain industry.

Our MISSION is to **"Conduct innovative research and develop new technologies to solve problems relating to natural resources conservation and the production, harvesting, storage, marketing, and utilization of grain to ensure a safe, abundant, and high quality grain supply."**

Located in Manhattan, Kansas, GMPRC is situated in the heart of the Great Plains, which includes thirteen states that produce more than 2/3 of all U.S. wheat, corn, sorghum, and soybeans. Operating from a 60,000 square foot facility and the nation=s only 50,000 bushel (700 metric ton) capacity research grain elevator, the Center is composed of five research units:

$ BIOLOGICAL
$ ENGINEERING
$ GRAIN QUALITY AND STRUCTURE
$ PLANT SCIENCE AND ENTOMOLOGY
$ WIND EROSION

Our VISION is to be **"The Customer=s Choice for solving problems in natural resources conservation and the production, harvesting, storage, marketing, and utilization of grain"** and we welcome the opportunity to serve all segments of the food industry from producers to consumers.

Dr. James E. Throne, Research Leader
Biological Research Unit

Dr. Floyd E. Dowell, Research Leader
Engineering Research Unit

Dr. Michael Tilley, Acting Research Leader
Grain Quality & Structure Research Unit

Dr. Robert L. Bowden, Research Leader
Plant Science & Entomology Research Unit

Dr. Edward L. Skidmore, Research Leader
Wind Erosion Research Unit

Dr. Donald E. Koeitzow
Center Director

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INTERACTIONS WITH KANSAS STATE UNIVERSITY

Kansas State University (KSU) has an exceptionally strong program in agricultural research and education. GMPRC maintains a close working relationship with KSU and the Kansas Agricultural Experiment Station and Cooperative Extension Service. One of the GMPRC research units, Plant Science and Entomology, is housed on the KSU campus. GMPRC scientists enjoy a close working relationship with scientists at KSU. A majority of the GMPRC scientists have adjunct faculty positions and, as a result, approximately 40 undergraduate and graduate students conduct research at GMPRC each year.

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Past Successes Present GMPRC with Three Golden Research Opportunities

Colorado Dust Storm 1937.

Kansas Dust Storm 2004.

Our past successes have presented us with three Golden Opportunities to have a major impact on U.S. agriculture. The exciting visions for these opportunities are presented below:

1. Protection of Our Land and Air Quality. Version 1.0 of the expert Wind Erosion Prediction System (WEPS) developed by scientists in our Wind Erosion Research Unit (WERU) was given to the Natural Resources Conservation Service (NRCS) in April 2005. We are currently working with NRCS to implement the use of WEPS to select land management practices that protect our soil from wind erosion. This will occur first in the Great Plains involving the major crops in this region and then be expanded to include the entire U.S. and over 60 different crops.

The Golden Opportunity: Wind erosion of the soil is a major problem in many parts of the world. In the U.S., over 50% of the 284 million acres of U.S. cropland are classified as AHighly Erodible Land.@ Each year, approximately 5 million acres are severely to moderately damaged by wind erosion. If allowed to continue, the sustainability of agriculture is threatened.

Results from current research with WEPS technology indicate that it accurately predicts soil losses from several current farming practices. This provides producers with information that can be used to adjust their management practices so that soil loss due to wind erosion is minimized. With additional modifications that include other farming practices, crops, soil types, weather conditions, etc., this technology has the potential of changing land management practices around the globe to dramatically decrease soil loss due to wind erosion. At the same time, it can be used to improve air quality by lowering the levels of small dust particles suspended in the air.

Other organizations and agencies such as the Department of Defense, the Environmental Protection Agency, the Forest Service, building construction groups, etc., are asking that the WEPS technology be modified so that it can be used to manage all different types of land such as forest meadows, military training grounds, and construction sites in order to protect our resources and maintain a healthy air quality. Preliminary results indicate that these expectations can be met. In addition, scientists from numerous countries including

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China, Mexico, Europe, and the Middle East are working with WERU in order to expand its use to the global community and, again, preliminary results are promising.

New sensors monitor grain quality in the bin.

2. Protection of Our Grain Quality and Safety. The U.S. must be able to ensure the quality and safety of the U.S. grain supply to remain competitive in domestic and foreign markets. In addition, both domestic and international grain customers are demanding greater consistency in their grain supplies and foreign competitors are reacting to meet these needs. If the U.S. is to remain competitive, we must develop rapid and accurate grain quality measurement systems that complement economical and practical storage and identity preservation techniques. To meet these industry needs, the Engineering Research Unit (ERU) has projects that include developing technology for rapid assessment of grain quality, and developing techniques for safe storage and rapid segregation of specific grain types.

The Golden Opportunity: A wide variety of sensors and other high-speed sorting and analysis equipment is now available to the grain and food processing industries. Most recently, ERU has begun to investigate the use of lasers for high-speed analytical systems which could greatly increase the speed, accuracy, and numbers of items that could be detected by these systems. Current research has shown that it is possible to detect genetically modified corn kernels, determine the presence of specific toxins produced by molds, and measure a wide variety of important end-use quality traits with this emerging technology.

Work must be done in order to determine how this new technology, including the laser-based systems, can be applied to solve problems in

High speed sorters can segregate grain using different quality selection criteria.

maintaining food safety, nutritional benefits, and quality. Numerous questions remain to be answered. Can we reliably detect the presence of acts of sabotage to grain stored in bins on the farm or that is passing through marketing channels? How fast can we detect the presence of toxins that may be present due to mold contamination? How much of a particular compound that is now known to promote improved health is present in a particular grain shipment? It is vital that the tools that can answer these questions and many others like them be affordable, rapid, reliable, and applicable at any point along the grain marketing channels including the first point of sale such as the country grain elevator.

Conducting this research program would require that the ERU expand their research capabilities in order to develop test methods and investigate sampling issues that can be used to quantify the amounts of specific traits such as the presence of transgenic kernels, bunted kernels of wheat, the presence of mycotoxins such as aflatoxin, and acts of bio-terrorism in a particular grain shipment.

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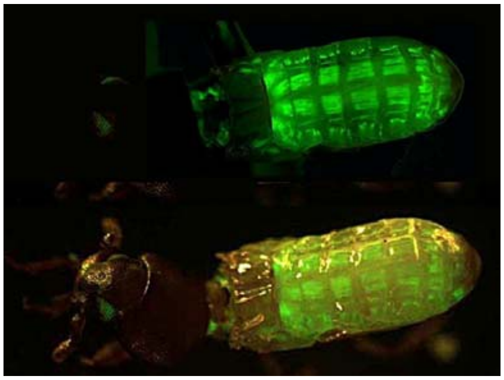
3. Control of Insect Pests in Our Food Supply. The annual value of U.S. wheat and corn crops is approximately $25 billion. It is estimated that losses due to insect pests range from 5 to 10% per year ($1.25 to $2.5 billion) and these estimates do not include damage to manufactured food products. They also do not include the estimated $1 billion that the food industry spends each year to control these pests. In addition, many current insecticides and fumigants may be lost to the cereal foods industry as registrations expire and regulations further limit chemical use. This will serve to increase the loss and damage of the U.S. food supply due to insect pest activities. Milling industries are under pressure to adopt alternatives to the use of the fumigant methyl bromide. Use of methyl bromide currently is subject to international approval through a Critical Use Exemption under the Montreal Protocol.

Scientists in our Biological Research Unit (BRU) have a long-term research program on the genomics of the red flour beetle (*Tribolium*) which is one of the most significant insect pests in our food supply in the U.S. This work led to a successful proposal to have the *Tribolium* genome sequenced by the Baylor College of Medicine as a national priority sponsored by NIH, and this sequencing was just completed.

The Golden Opportunity: The red flour beetle is the first agricultural insect pest to have its genomic structure sequenced. Beetles are the most numerous animals in the world and are the most numerous agricultural pests in the U.S. and throughout the world; thus, the information obtained from work with the red flour beetle should be applicable to many pest and beneficial beetle species. In fact, the red flour beetle is the number one insect pest in flour mills in the U.S., and the milling industry has great interest in new methods for more effectively controlling this pest. We need to mine the genomic information on the red flour beetle for potential pest control solutions, and we anticipate that this work will identify new targets in insects that can be exploited for insect control, just as sequencing the human genome has provided new targets for controlling disease and understanding other physiological processes in humans.



Modified red flour beetles showing muscle proteins synthesized by specific genes.

In order to mine the information from these genomic results, we need to increase our expertise in Bioinformatics. Complete development of new insect pest control technology will also depend on our increasing our efforts in Food Processing Pest Management, Pheromone Development (these are chemicals that attract insects in monitoring programs), and Insect Immunology (expertise in exploiting the insect immune system for weaknesses). The activities in food processing pest management and pheromone development will fulfill needs expressed by U.S. food processors for developing better pest management programs to alleviate the need for methyl bromide fumigations. The activities in bioinformatics and insect immune systems are likely to yield new targets for pest

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control that will serve as the basis for new management methods in the future.

Major Center Renovation Kick-Off Celebration Featured Senator Pat Roberts. On January 13, the Center hosted a Renovation Ceremony featuring Senator Pat Roberts as the keynote speaker. Other speakers included Riley Scott, Legislative Aide for Senator Sam Brownback; Rodney Brown, USDA Deputy Under Secretary for Research, Education, and Economics; Jon Wefald, President of Kansas State University; Will Blackburn, ARS Director of the Northern Plains Area; Adrian Polansky, Kansas Secretary of Agriculture; and Mr. Lyle Butler, President and CEO of the Manhattan Chamber of Commerce. Senator Roberts and his staff were instrumental in obtaining the $14.8 million needed for this renovation project. During the project, all heating, air conditioning, electrical, gas, air, and water services in the facility will be replaced and a new peaked roof will be added. Visitors and ceremony participants toured the existing facility and received updates of the ongoing research of each of the Units comprised in the Center.

Senator Pat Roberts provides keynote address at renovation ceremony.

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Progress Report Designed for Customers

This Progress Report is designed to provide specific information about each of the active research projects at GMPRC in terms that are easily understood. This is the first year that we will be providing this report on a CD that is searchable.

Each major research project in the Agricultural Research Service, including those at GMPRC, is identified by a number from the Current Research Information System (CRIS). In addition, we frequently develop Specific Cooperative Agreements (SCAs) or Cooperative Research and Development Agreements (CRADAs) with other groups such as universities, other federal agencies, or private companies. All of the results from these various agreements are incorporated into the report for each of the specific CRIS projects that they are associated with.

The information in this Progress Report is organized by Research Unit and a complete Table of Contents is provided on the following pages. For each project described, we have provided a statement of the problem that we are trying to solve, the goals and objectives for this particular research activity, the results obtained during 2005, and our future goals for this research activity for the next three years. We also have included a list of publications along with a contact person if the reader has additional questions or needs more detailed information on a project.

We certainly appreciate your comments and suggestions concerning ways that we can improve this report especially since this is the first year it is available on CD. We encourage you to continue to send your comments via mail, telephone, FAX, or email to:

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BIOLOGICAL RESEARCH UNIT

The mission of the Biological Research Unit is to develop new and improved methods, approaches and strategies for the management of insect pests that attack grain and stored products. In order to decrease the levels of chemical pesticides used to protect our food supply, safer more effective alternatives must be developed. Specific research projects for this Unit include:

CRIS - 5430-43000-025-00D	Integrated Management of Insect Pests in Stored Grain and in Processed Grain Products
CRIS - 5430-43000-026-00D	Genomics and Proteomics of Stored-Product Insects for Development of New Biopesticides
CRIS - 5430-43000-027-00D	Ecology, Sampling, and Modeling of Insect Pests of Stored Grain, Processing Facilities, and Warehouses

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CRIS 5430-43000-025-00D

Integrated Management of Insect Pests in Stored Grain and in Processed Grain Products

Project Leader: F. Arthur

Investigators: F. Arthur and J. Lord

Full-Time Scientist Equivalents (SYs): 2.0

Start Date: 04/06/05

Term Date: 04/05/10

Problem: Insect pests can contaminate and destroy stored food products, thereby decreasing food quality and reducing the confidence of consumers. Worldwide estimates of product losses due to these pests range from 10 to 15% in temperate climates to more than 30% in sub-tropical and tropical climates. In the U.S., cost estimates for this damage range from $1.5 to 3.0 billion per year.

There is a need to improve integrated pest management (IPM) of stored-product insects by identifying new reduced-risk control agents and the factors that affect susceptibility to those agents, maximizing the effects of control strategies through synergistic combinations, developing new approaches for application and integration of control strategies, and determining vulnerabilities in physiological and biochemical responses that could affect susceptibility to various control agents. Insect pathogens are potential additions to integrated management programs for stored products, but they may not give effective control by themselves. However, control could be enhanced through synergies and disruption of insect immune systems. The loss of methyl bromide also presents a need to investigate specific targeted applications in storage structures as an alternative to fumigation. Our goal is to improve IPM of stored-product insects through selective targeting of alternative insecticides, biologically-based control methods, and physical controls, and by identifying vulnerabilities in insect immune systems that could be exploited to improve the effectiveness of control strategies.

Objectives: This research has three major objectives: 1) Identify and refine alternative insecticides, biologically-based control methods, and physical controls to manage stored-product insect pests; 2) Evaluate selective targeted controls and application strategies to manage insect pests in different stored-product systems; and 3) Identify vulnerabilities in insect physiological and biochemical stress responses that could be exploited to improve the effectiveness of reduced-risk controls, biological agents, and physical control methods.

Results and Impact:

1. Aeration for Insect Control in Kansas Stored Wheat – a Real Test. Insect pests often cause economic damage in stored grain, and cooling storage bins in autumn through aeration (using low-volume airflow rates of ambient air) can be an important component of integrated management plans for stored wheat. Model simulation studies show that a summer aeration cycle would cool stored wheat in Kansas and also reduce insect populations, but field studies have not been done to verify model predictions. We

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conducted a 3-year study in which summer aeration was included along with aeration in early and late autumn. The additional summer aeration cycle lowered grain temperatures and reduced natural insect populations compared to bins with autumn aeration only. Results confirmed modeling studies which predicted lower insect populations in grain aerated during the summer. Additional research is being conducted to determine if the direction of airflow (pushed into the bin versus sucked out of the bin) improves the efficiency of summer aeration.

2. How Can We Locate the Natural Enemies of Grain Insect Pests? Naturally occurring insect pathogens can attack storage pest insects and decrease their populations, but the existing tools for measuring the impacts of these attacks are inadequate to assess their impacts. Better detection tools are needed in order to monitor pathogen prevalence in controlled experiments and wild populations so that decisions can be made regarding pathogen preservation or introduction for pest suppression. We obtained highly specific monoclonal antibodies to two widely-occurring pathogens and developed serological assays that will rapidly detect pathogen presence in large numbers of insects. One assay detects a pathogen of rusty and sawtoothed grain beetles and differentiates this pathogen from closely related benign microbes that normally inhabit beetle intestines. The other can be used to detect a disease of Indianmeal moths and Mediterranean flour moths. These assays can be used in controlled experiments and environmental monitoring to determine the impact of these beneficial organisms and to find ways to integrate them into insect pest control programs. They can also be used to detect disease in laboratory colonies.

3. Stress Improves Pathogen Effectiveness Against Stored-Product Insects. The stored-product environment has relatively dry conditions that are generally believed to be an impediment to the use of fungal insecticides. We have discovered that a commercial fungal insecticide is more effective against some key insect pests of stored products in low moisture environments than in high moisture environments. For example, a reduction of relative humidity from 75% to 43% can result in a 10-fold increase in fungal effectiveness in attacking lesser grain borers. Increases in effectiveness with lowered humidity have also occurred with red flour beetles and Indianmeal moths. This is probably due to desiccation stress and enhanced survival of the spores. In addition, exposure to desiccation stress prior to exposure to the fungus also increases fungal effectiveness. These results show how performance of a non-chemical approach to insect control could be improved through manipulation of stress factors, such as is done with controlled atmosphere strategies, and provide a means to identify other stress factors that impact the effectiveness of fungal pathogens.

4. Hydroprene Works on Indianmeal Moth. Hydroprene is an insect growth regulator used for control of stored-product insects, but there are no data to show that this insecticide can control late-stage larvae of the Indianmeal moth, a major pest of stored food. Of the five larval stages, this final stage, called the wandering phase, is generally the most difficult to kill with residual insecticides. We exposed last instar larvae of the Indianmeal moth on concrete treated with the label rate of hydroprene. This exposure to hydroprene either arrested the last stage larva or prevented adult emergence, depending on the amount of time the larvae were exposed. Hydroprene is a reduced-risk insecticide, and could replace conventional neurotoxic insecticides currently used to control the Indianmeal moth in storage facilities.

5. Pest Insects Defeat Diatomaceous Earth Treated Layers of Wheat in Grain Bin. Stored wheat is often treated with the inert dust diatomaceous earth (DE) by mixing the dust into the top surface of the wheat mass, but there are no data to show if this method of application would effectively control the lesser grain borer, a major pest of stored wheat. We put 6-, 9-, and 12-inch layers of treated wheat on top of untreated wheat in a vertical column, and released live adult lesser grain borers on the surface. Adult mortality increased with increasing depths of the DE-treated layer, as expected, but adults were able to penetrate through the DE-treated layer and lay eggs and produce progeny in the untreated wheat. Diatomaceous earth used as a surface treatment did not completely protect wheat from the lesser grain borer. Other reduced-risk insecticides should be combined with DE to control the lesser grain borer in stored grain.

6. Parasitoid Venom May Aid in Insect Control. Dufour glands in Hymenoptera (small parasitic wasps) produce a wide variety of active chemicals that can affect the behavior of these insects. A detailed characterization of these compounds in parasitoids associated with pest insects of cereals is lacking. We collaborated with scientists at Montana State University, in the analysis of chemical components from the small exocrine glands associated with the venom complex in two parasitic wasps that attack beetle pests. Four chemical classes were detected in individual glands, with major components being acetate esters and long chain monenes, dienes, and trienes. These compounds could be manipulated to attract more biological control agents, such as parasitic wasps, to wheat and other commodities infested with pest insects.

Goals for 2006, 2007, and 2008:

Specific tasks in 2006 will be to:

1. Evaluate the insect growth regulator, methoprene, alone and in combination with diatomaceous earth, to control the lesser grain borer in stored grains.

2. Evaluate new techniques for using the pathogens *Beauveria* and *Mattesia* as biological controls in stored grain. Assess the prevalence of these pathogens in natural and experimental populations of stored-product insect pests.

3. Conduct bioassays of physical controls, including heat and diatomaceous earth, combined with pathogens to control pest insects in stored grain.

4. Initiate a field project to determine optimal airflow direction (either pulled through the grain mass or pushed into the grain mass) for summer aeration in stored wheat.

5. Evaluate new reduced-risk insecticides as surface treatments to floors and walls of milling facilities.

6. Prepare micro-assays to identify genes involved in insect responses to pathogens and stress and develop experimental protocols for initial experiments on gene activation in pest insect immune and stress responses.

Specific tasks in 2007 will be to:

1. Continue with on-going insect growth regulator (IGR) evaluations, analyze data from completed studies with hydroprene and

methoprene on surface substrates, and present results of insect control using IGRs to industry and other user groups.

2. Correlate stress responses of stored-product pest insects with pathogen susceptibility, and continue with studies involving combination treatments with pathogens.

3. Expand current research with combinations of IGRs and DE as surface treatments on wheat to other stored grains such as rice and corn.

4. Obtain a second year of data for the directional airflow study with summer aeration on wheat in storage bins.

5. Conduct field studies with targeted insecticide treatments in raw stored grain and in milling facilities.

6. Continue with data collection for prevalence of stored grain insects and with the parasite-pathogen combination study.

7. Quantify genetic responses to pathogens, heat treatments, and other physical controls.

Specific tasks in 2008 will be to:

1. Gather a final year of data for the summer aeration study of wheat in storage bins, and conduct additional evaluations of targeted insecticide treatments in stored products.

2. Gather additional data for pathogen prevelance and conduct expanded tests with combination treatments of reduced-risk insecticides with physical controls and with parasitic wasps.

3. Model the effectiveness of *Mattesia* to suppress specific stored-product insect species.

4. Develop experimental protocols to measure insect immune responses and document susceptibility of insects with silenced (altered) immune response genes to pathogens.

Specific Cooperative Agreements for This Project Included:

a. The Department of Entomology, Kansas State University, Manhattan, Kansas

b. The Department of Food Science, University of Arkansas, Fayetteville, Arkansas

c. The Department of Entomology and Plant Pathology, Oklahoma State University, Stillwater, Oklahoma

Summary of 2005 Publications/Patents:

1. Huang, F., Subramanyam, B., Toews, M.D. Susceptibility of laboratory and field strains of four stored product insect species to spinosad. 2004. Journal of Economic Entomology v. 97. p. 2154-2159.

2. Baker, J.E., Howard, R.W., Morrill, W., Meers, S., Weaver, D. Acetate esters of saturated and unsaturated alcohols (c12 to c20) are major components in Dufour glands of *Bracon cephi* and *Bracon lissogaster* (Hymenoptera: Braconidae), parasitoids of the wheat stem sawfly, *Cephus cinctus*. 2004. Biochemical Systematics and Ecology v. 33. p. 757-769.

3. Akbar, W., Lord, J.C., Nechols, J.R., Loughin, T.M. Efficacy of *Beauveria bassiana* for the red flour beetle, *Tribolium castaneum*, when applied with plant essential

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oils or in mineral oil and organosilicone carriers. 2005. Journal of Economic Entomology v. 98. p. 683-688.

4. Hartzer, K.L., Zhu, K., Baker, J.E. Phenoloxidase in larvae of *Plodia interpunctella* (Lepidoptera: Pyralidae): molecular cloning of the proenzyme cDNA and enzyme activity in larvae paralyzed and parasitized by *Habrobracon hebetor* (Hymenoptera: Braconidae). 2005. Archives of Insect Biochemistry and Physiology v. 59. p. 67-79.

5. Howard, R.W., Blomquist, G.J. Ecological, behavioral, and biochemical aspects of arthropod hydrocarbons. 2005. Annual Review of Entomology v. 50. p. 371-393.

6. Lord, J.C. From Metchnikoff to Monsanto and beyond: the path of microbial control. 2005. Journal of Invertebrate Pathology v. 89. p. 19-29.

7. Lord, J.C. Low humidity, moderate temperature, and desiccant dust favor efficacy of *Beauveria bassiana* (Hyphomycetes: Moniliales) for the lesser grain borer, *Rhyzopertha dominica* (Coleoptera: Bruchidae). 2005. Biological Control v. 34. p. 180-186.

8. Toews, M.D., Arthur, F.H., Campbell, J.F. Role of food and structural complexity on capture of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) in simulated warehouses. 2005. Environmental Entomology v. 34. p. 164-169.

9. Toews, M.D., Campbell, J.F., Arthur, F.H., West, M.S. Monitoring *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) in pilot scale warehouses treated with residual applications of (s) hydroprene and cyfluthrin. 2005. Journal of Economic Entomology v. 98. p. 1391-1398.

10. Toews, M.D., Phillips, T.W., Payton, M. Estimating populations of grain beetles using probe traps in wheat-filled concrete silos. 2005. Environmental Entomology v. 98. p. 1391-1398.

For More Information on This Project Contact:

Dr. Frank Arthur
Telephone - 1-800-627-0388 or (785) 776-2783
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email – frank.arthur@gmprc.ksu.edu

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CRIS 5430-43000-026-00D

Genomics and Proteomics of Stored-Product Insects for Development of New Biopesticides

Project Leader: R. Beeman

Investigators: R. Beeman and B. Oppert

Full-Time Scientist Equivalents (SYs): 2.0

Start Date: 04/06/05

Term Date: 04/05/10

Problem: Stored-product insects cause numerous problems throughout grain production and marketing channels. These pests are detrimental to commodity nutritional value, consumer acceptance, and end-use performance. As value is added to these commodities, losses become even more significant. Because export markets depend on high quality products, any reduction in grain quality will result in loss of economic benefits to the American farmer and processor. Novel pest management practices are needed to prevent spoilage or contamination by post-harvest pests and pathogens and to conserve resources and maintain commodity quality during handling, conditioning, storage, and processing.

Traditional chemical controls used by the cereal foods industry are being lost due to insect resistance, reduced public acceptance, and changes in regulatory oversight. There remain major gaps in our basic knowledge of genetic and physiological mechanisms for insect perception of and response to environmental cues, and for insect growth, development, digestion, metabolism, and survival. These knowledge gaps are hampering the development of new integrated management strategies for stored-product insect pests. The need for novel systems of insect control based on knowledge of basic insect physiology, biochemistry, molecular biology and genetics coincides with recent, unprecedented advances in genomic analysis of pest insects, which can fuel the growth of such knowledge.

Objectives: This research has three major objectives: 1) Develop new genomic, proteomic, and transgenic technologies for discovering novel biological targets that can be used to control pest insects; 2) Characterize vulnerable genetic and physiological pathways such as those involved in digestion, osmoregulation (body fluid regulation), and immunity; and 3) Develop DNA fingerprinting technologies for identifying populations and infestation sources, and for incorporation into integrated pest management (IPM) systems for stored-product insects.

The proposed research will increase our knowledge of gene families and protein pathways that regulate vital physiological processes in insect tissues. Attaining these objectives will reveal novel protein targets and could lead to safer, more selective inhibitors for insect pest control. Knowledge of the structure of the *Tribolium* genome will lead to rapid advances in our understanding of the biology of pest insects and lead to new control strategies for other insect pests. Genome analyses also will foster improvements in molecular fingerprinting of insects, leading to a better understanding of

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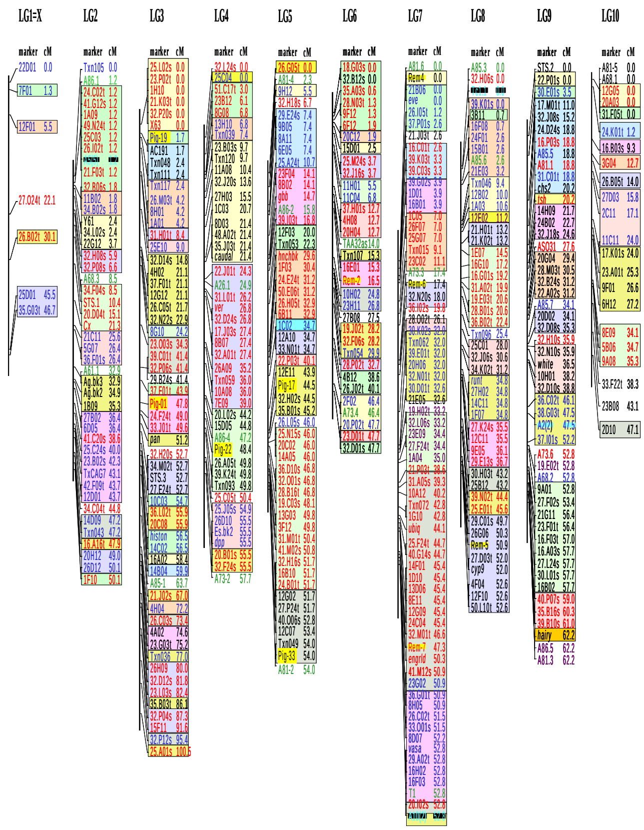
the structure and dynamics of insect populations.

Expected products include improved biocontrol agents that block molting, stop reproduction, or inhibit digestion. In addition, discovery of novel gene and protein targets such as those involved in the insect response to changes in the environment may lead to the development of new lines of cereal grains that are more resistant to insect pests. New DNA fingerprinting methods will facilitate monitoring of insect pest population movements and more accurate identification of sources of infestation and pest resurgence.

Results and Impact:

1. Red Flour Beetle Is FIRST Agricultural Pest to Have Genome Sequenced. The genome of a living organism contains all of the genes (made from DNA) needed by the organism to survive. Modern genetic tools make it possible to determine the structure of the DNA contained in the genome of a living organism and this provides a tremendous amount of information about the specific processes that the organism needs to survive.

The red flour beetle is an important pest of harvested grain and grain products. It also is the first agronomic pest species to be sequenced and represents the joint efforts of the Biological Research Unit in Manhattan, KS; Kansas State University; and the Baylor College of Medicine's Human Genome Sequencing Center. Genetic tools were used to pimpoint the chromosomal locations of over 75% of the genes in the genome of this organism so far, with the rest to follow in the next few months. The analysis of this genome will have far-reaching impact on our knowledge of insect genome evolution, physiological adaptations in pest and beneficial beetle species, and the identification of novel targets for the development of improved pest control methods.



Chromosome maps of the red flour beetle.

2. New Genome Manipulation Tools Developed Using Red Flour Beetle Model System. One of the best ways to learn about a gene's normal functions is to knock out the gene and see what functions are disrupted. Transposons are short DNA segments that can be inserted into normal genes to interrupt their functions. Two example of a specific transposons found in nature are called piggyback and Minos. Promoters are additional pieces of DNA that help initiate and facilitate the insertion of transposons.
In collaboration with Kansas State University and the Universities of Erlangen and

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Gottingen, Germany, we generated two new transgenic helper lines that employ highly active, naturally occurring red flour beetle (*Tribolium)* promoters (polyubiquitin and alpha-tubulin) to produce high levels of the enzymes (called transposases) that catalyze the insertion of the piggyback and Minos transposons. These new genetic strains could make it possible to knock out selected genes at a very high efficiency.

This will greatly facilitate the determination of the normal functions of each gene in the *Tribolium* genome. Tools such as this will be vital for functional analysis of insect genes and, subsequently, will help us design unique biopesticides that can be used to control insect pests.

3. Insect Exoskeleton Now a Target for Insect Control. Since insects do not have an internal skeleton made of bones, their body structures are held in place by an exterior shell known as an exoskeleton. When this material is first synthesized, it is soft and pliable. Over time, it hardens and turns dark in a process that is referred to as tanning.

In 2005, we put to rest a long-running controversy by identifying the insect tanning enzyme. It had long been suspected that the tanning enzyme was a member of the laccase-tyrosinase family, but positive identification of the specific enzyme responsible for hardening and darkening of the insect exoskeleton had eluded researchers until now.

We used genetic manipulation tools (specifically RNAi-mediated, genespecific knockout) to demonstrate that the enzyme laccase-2 alone is necessary and sufficient for cuticle tanning. Without this enzyme, the exoskeleton does not harden as it should and the insects can not survive. As a result, the gene that produces laccase-2 is an excellent candidate for biopesticide-mediated control of this important insect pest, and this breakthrough adds to the list of candidate genes for pest control targeting.

Red flour beetle with normal laccase-2 (left) and with laccase-2 knocked out by RNAi (right).

4. Studies of Gene Expression in Yellow Mealworm Intestine Lead to New Potential Insect Control Techniques. The gut is a major battle ground between plant substances that inhibit insect digestive proteins and the insect's response to develop new digestive proteins. As plants produce new inhibitors, insects must change to produce different digestive enzyme systems in order to survive. As a result, using the information from studies of how insects adjust to produce these new digestive enzymes, we may be able to design combinations of enzyme inhibitors that can serve as new control techniques.

We have developed a library of over 1400 gene sequences that were expressed in the gut of the yellow mealworm (*Tenebrio molitor).* Many of the DNA sequences obtained are similar to those for very well known digestive enzymes including chymotrypsin, trypsin, elastase, and cathepsin B and L, as well as other important gut genes. These sequences will be used to study gene regulation in response to dietary inhibitors so that new control inhibitors can be developed.

A comparison indicated that most of the yellow mealworm genes examined are very similar to those found in the red flour beetle (*T. castaneum)* genome. Therefore, new inhibitor combinations that work in the yellow mealworm have a high probability of also working to inhibit the digestive enzymes in other pest insects such as the red flour beetle.

Goals for 2006, 2007, and 2008:

Specific tasks in 2006 will be to:

1. Complete the genetic and physical maps of the Tribolium genome and the integration and reconciliation of these maps with the genome sequence.

2. Initiate manual adjustment of the automated genome annotation (scheduled for release in the near future) and continue gene discovery and compilation of gene lists.

3. Continue generating and characterizing transposon insertion lines, and continue improvement of gene tagging and mutagenesis systems.

4. Initiate screening of transposon insertion libraries for enhancer patterns, stress tolerance, developmental and molting defects, pesticide resistance, or other traits.

5. Continue sequencing and identification of genes that function in digestion, neurotransmission, osmoregulation, and other vital life processes.

6. Continue identification of target gene families from genome annotation.

7. Continue RNAi knockout from priority genelists.

8. Design microarray experiments for whole-genome scanning of gene function.

9. Maintain data-stream into BeetleBase.

10. Initiate toxin bioassays in coleopteran pests.

11. Develop improved microsatellite and other DNA fingerprint markers for analysis of local and regional populations.

Specific tasks in 2007 will be to:

1. Continue manual adjustment of genome annotation and gene discovery.

2. Complete testing of promoters and transactivators and incorporation into vectors for gene tagging, enhancer trapping and misexpression.

3. Enter data for insertional mutagenesis library into BeetleBase.

4. Conduct Northern and qPCR analysis of proteinase gene expression.

5. Initiate comparison of Bt toxin binding proteins in coleopteran pests.

6. Initiate proteinase studies with Bt toxins. Initiate microarray experiments.

7. Maintain data-stream into BeetleBase.

Specific tasks in 2008 will be to:

1. Continue manual adjustment of genome annotation and gene discovery.

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2. Complete screening of insertional mutant libraries for physiological defects, enhancer patterns, or other traits.

3. Design new biopesticides based on proteinase inhibitor and toxin binding studies.

4. Conduct microarray analyses using oligo-based hybridization.

5. Develop theories of population structure of stored-product beetles.

Specific Cooperative Agreements for This Project Included:

a. The Departments of Biochemistry, Biology, and Entomology at Kansas State University, Manhattan, Kansas

b. The Human Genome Sequencing Center at the Baylor College of Medicine in Houston, Texas

Summary of 2005 Publications/Patents:

1. Arakane, Y., Muthukrishnan, S., Beeman, R.W., Kanost, M.R., Kramer, K.J. Laccase 2 is the phenoloxidase gene required for beetle cuticle tanning. 2005. Proceedings of the National Academy of Sciences v. 102. p. 11337-11342.

2. Dittmer, N.T., Suderman, R.J., Jiang, H., Zhu, Y., Gorman, M.J., Kramer, K.J., Kanost, M.R. Characterization of CDNAs encoding putative laccase-like multicopper oxidases and developmental expression in the tobacco hornworm, *Manduca sexta*, and the malaria mosquito, *Anopheles gambiae*. 2004. Insect Biochemistry and Molecular Biology v. 34. p. 29-41.

3. Goodwin, T.J., Poulter, R.T., Lorenzen, M.D., Beeman, R.W. DIRS retroelements in arthropods: identification of the recently active TcDirs1 element in the red flour beetle, *Tribolium castaneum*. 2004. Molecular and General Genomics v. 272. p. 47-56.

4. Kramer, K.J. Avidin, an egg-citing insecticidal protein in transgenic corn. In: Liang, G.H., Skinner, D.Z., editors. 2004. Genetically Modified Crops, Their Development, Uses, and Risks. Food Products Press, The Haworth Press, Inc., Binghamton, NY, p. 119-130.

5. Li, H., Oppert, B.S., Higgins, R.A., Huang, F., Buschman, L.L., Zhu, K. Susceptibility of dipel-resistant and -susceptible *Ostrinia nubilalis* (Lepidoptera: Crambidae) to individual *Bacillus thuringiensis* protoxins. 2005. Journal of Economic Entomology v. 98. p. 1333-1340.

6. Oppert, B.S., Morgan, T.D., Hartzer, K.L., Kramer, K.J. Compensatory proteolytic responses to dietary proteinase inhibitors in the red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). 2005. Comparative Biochemistry and Physiology, Part C v. 140. p. 53-58.

7. Tsybina, T.A., Dunaevsky, Y.E., Belozersky, M.A., Zhuzhikov, D.P., Oppert, B.S., Elpidina, E.N. A cationic trypsin-like proteinase from the midgut of *Tenebrio molitor* larvae. 2005. Biochemistry (Moscow) v. 70. p. 300-305.

8. Vinokurov, K.S., Oppert, B.S., Elpidina, E.N. An overlay technique for post electrophoretic analysis of proteinase spectra in complex mixtures using p-nitroanilide substrates. 2005. Analytical Biochemistry v. 337. p 164-166.

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9. Yoza, K., Imamura, T., Kramer, K.J., Morgan, T.D., Yaguchi, M., Nakamura, S., Kawasaki, S., Takaiwa, F., Ohtsubo, K., Beeman, R.W. Avidin expressed in transgenic rice confers resistance to the stored-product insect pests, *Tribolium confusum* and *Sitotroga cerealella*. 2005. Bioscience Biotechnology and Biochemistry v. 69. p. 966-971.

10. Zhu, Y., Liu, X., Maddur, A., Oppert, B.S., Chen, M. Cloning and characterization of chymotrypsin- and trypsin-like cDNAs from the gut of the Hessian fly (*Mayetiola destructor* (say)). 2005. Insect Biochemistry and Molecular Biology v. 35. p. 23-32.

11. Zimoch, L., Hogenkamp, D.G., Kramer, K.J., Muthukrishnan, S., Merzendorfer, H., Beeman, R.W. Regulation of chitin synthesis in the larval midgut of *Manduca sexta*. 2005. Insect Biochemistry and Molecular Biology v. 35. p. 515-527.

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CRIS 5430-43000-027-00D

Ecology, Sampling, and Modeling of Insect Pests of Stored Grain, Processing Facilities, and Warehouses

Project Leader: P. Flinn

Investigators: J. Campbell, P. Flinn, and J. Throne

Full-Time Scientist Equivalents (SYs): 3.0

Start Date: 04/28/05

Term Date: 04/27/10

Problem: Insects reduce the quality of stored grain and other stored products in the U.S. and in other parts of the world. Over 12 billion bushels of corn and wheat are grown in the U.S. each year, with a value of over 25 billion dollars. In addition, over a billion bushels of barley, oats, rice, rye, and sorghum are grown in the U.S. each year, with a value of over 3 billion dollars. It is estimated that post-harvest losses to corn and wheat due to insects are 5 to 10%, or about 1.5 to 3.0 billion dollars. In addition, food industry estimates of the costs for controlling these insect pests are approximately 1 billion dollars per year.

Losses to processed commodities are difficult to quantify, but probably greatly exceed the losses to raw commodities. Many of the insecticides used by the cereal foods industry are being lost due to insecticide resistance or regulatory changes. Thus, alternative, economically viable methods for controlling these insects and reducing losses to raw and processed commodities are required. Our goal is to improve the integrated pest management (IPM) of stored-product insects through development of better monitoring methods and use of computer models to optimize control strategies.

Objectives: This project has four main goals: 1) Improve insect detection, sampling, and monitoring techniques in raw grain, grain processing facilities, and warehouses; 2) Characterize factors responsible for insect pest resurgence after fumigation or other treatments; 3) Develop computer simulation models for insect pests of grain processing facilities and warehouses, and use these models to optimize monitoring and management strategies; and 4) Investigate the ecology and the potential economic impact of emerging pest species, such as psocids and grain mites.

Attaining these objectives will provide benefits to managers of grain storage and grain processing facilities, food warehouses, and retail stores and to consumers by optimizing monitoring and management strategies for stored-product insect pests. Pest resurgence after control treatments is a major problem for the grain processing industries, and this research will improve our understanding of that problem. The research will determine the importance of emerging pests, such as psocids and mites.

Anticipated products are improved insect monitoring and sampling technologies, improved interpretation methods for sampling and monitoring systems, new computer simulation models that can be used to

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optimize monitoring and management strategies in grain storage and processing facilities, strategies for avoiding pest resurgence after control treatments are applied, and new information regarding the prevalence and environmental conditions that cause outbreaks of emerging pests, such as psocids and grain mites.

Results and Impact:

1. Most Insect Fragments in Flour Come from Adults and Can Be Detected by Near-Infrared Spectroscopy. The milling industry routinely checks flour for insect fragments to determine whether the level is below the FDA defect action level (75 fragments/50 g flour). However, the standard chemical extraction method used to detect insect fragments in flour is costly and time-consuming; thus, a rapid detection method is desirable.

In addition, little is known about differences in the number of fragments produced from different stages of different insect species. We determined that wheat infested with a single adult lesser grain borer contributed 28 times and 10 times as many fragments as wheat infested with a single larva or pupa, respectively. Using regression models that we developed from these data, we predicted that 1-kg samples of wheat with more than 20 kernels infested with adult borers would be above the FDA defect action level for insect fragments; similarly, it would take an infestation level of 300-500 kernels (in a 1-kg sample) containing larvae or pupae to exceed the defect action level.

We also determined the accuracy and sensitivity of near infrared spectroscopy (NIRS) for detecting insect fragments in flour using three different NIR spectrometers The Cognis-QTA™ FT-NIR spectrometer gave the best estimates of insect fragment levels in

A lesser grain borer larva and pupa in partially dissected wheat kernels, and an adult in flour.

flour samples in our tests. For a model combining data for all life stages (larvae, pupae, and adults), the QTA spectrometer would not be able to determine whether fragment counts were above or below the defect action level when actual fragments in a 60-g sample were between 46 and 135; similar levels for the Perten Diode Array 7000 and Foss NIR Systems 6500 spectrometers were 30 – 146 and 9 – 164. We used 60-g samples because this was the flour yield from our wheat samples, and we did not want to bias the fragment counts by subsampling. Thus, a fragment count in a 60-g sample that would be comparable to the FDA defect action level would be 90 fragments in 60 g of flour. The QTA spectrometer may have yielded the best predictions of the number of fragments in samples because the QTA spectrometer continuously mixed the flour sample while collecting spectra whereas the other spectrometers sampled a static sample. In addition, the QTA and Perten spectrometers collect spectra for the whole sample, while the Foss spectrometer collects spectra for only a portion of the sample. NIRS was less precise than the standard flotation method, but it has the advantages that it is rapid, nondestructive, does not require extensive sample preparation, and can be automated for a more sophisticated sampling protocol for flour.

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2. Beneficial Insects Control Indianmeal Moth. Three species of parasitoid wasps that attack the eggs of the Indianmeal moth were evaluated for their potential to serve as biological control agents in retail stores. The presence of packages on the shelves didn't affect the foraging activities of two of the three species tested. The most effective wasp species was *Trichogramma deion*. This species caused approximately 70% mortality to Indianmeal moth eggs compared to the control. Since these parasitoid wasps are so small that they are barely visible, they may serve as an effective method for controlling levels of the Indianmeal moth in retail stores.

***Trichogramma* parasitoid wasp.**

3. Treatment of Stored Corn with Combination of Avidin Corn Powder and Beneficial Insects Controls Insect Pests. The protein avidin (found in chicken eggs) is toxic to many of the insect pests that attack our grain supply. Transgenic corn that contained the avidin gene from chickens was ground into a powder and tested to see if this formulation alone or in combination with parasitoid wasps was effective at controlling insect pests that feed on stored grain. The combination treatment of avidin corn powder plus the release of parasitoid wasps was superior to either treatment alone when tested against mixed populations of the internal feeder, *S. zeamais*, and the external feeders, *T. castaneum* and *C. ferrugineus*. Normally, multiple insect species that are both external and internal feeders are found in stored grain. While avidin corn powder is fairly effective as an insecticide against the external feeders, it is not very effective against the internal feeders. By using the combination treatment, stored grain managers would be assured of protection from both internal and external feeders. The advantage of using this particular wasp species is that by releasing only *Theocolax elegans*, it would control most of the insect species that are internal feeders in stored grain. Avidin corn powder could then be used in a combination treatment to suppress most of the insects that are external feeders, such as *C. ferrugineus*, *T. castaneum*, and *O. surinamensis*.

***Theocolax elegans* attacking beetle larvae inside wheat kernels.**

4. Perimeter Insecticide Treatments Have Minimal Impact on Red Flour Beetles in Hidden Refugia. In commercial food facilities it is difficult to evaluate the effectiveness of pesticide treatments due to problems in both directly treating pests and determining pest population levels using pheromone trapping because stored-product insects tend to be hidden in refugia. In a pilot-scale warehouse study, where shelf units were artificially infested with red flour beetles and

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then two application methods of the pesticides (S)-hydroprene and cyfluthrin were applied, it was demonstrated that there were significantly more dead adults and lower trap captures in warehouses treated with cyfluthrin than with (S)-hydroprene or water (control treatment). However, food patch samples showed no detectable differences in number of insects among any treatments. These results show that perimeter treatments had minimal impact on the pest populations in hidden refugia, but could cause significant mortality to dispersing adults and reduce pheromone trap captures. These are important findings for both the application of surface treatments and the interpretation of monitoring programs by pest management professionals in food facilities such as retail stores.

Experimental shed where perimeter treatments are tested.

5. The Costs and Benefits of Multiple Mating by the Rice Weevil. The number of offspring produced by an insect is often a function of the number of matings that females receive, but variation in the costs and benefits of multiple mating can have wide-ranging implications for pest behavior and ecology. For rice weevil, a major pest species of stored grain, a single copulation did not enable females to lay eggs over their complete lifespan, so additional copulations did increase the number of offspring that a female could produce. However, this was true only up to a point; as the number of males increased there was a decline in number of offspring produced and the length of the female lifespan. This conflict between males and females could influence pest population dynamics and movement patterns in grain, ultimately impacting monitoring programs and predictions of pest population dynamics.

6. Computed Tomography Detects Internal Feeding Stored-Product Insects. Computed tomography is a technique used in the medical profession in which a series of x-rays of different layers through a patient are combined to produce a three-dimensional picture. We have modified this technique for use on grain samples to provide a rapid, accurate method for detecting and quantifying the number of insect-infested cereal grains. We developed a novel protocol utilizing computed tomography and an automated detection program to scan and process 300-g samples of wheat in less than two minutes. The average detection accuracy in samples containing 5 infested kernels per 100 g of wheat was 94.4%. These results are the first step toward developing next-generation computerized equipment to rapidly detect insects in many types of cereal grains and beans.

7. Rubber Gaskets Decrease Insect Migration into Facility by Factor of Three. Migration of stored-product insect pests into grain storage and processing facilities is often underappreciated when developing a pest management program. We tested installing rubber door gaskets to mitigate insect immigration around overhead doors. Using unbaited sticky traps positioned inside the doors, we showed that the number of beetles captured on the cards decreased by a factor of three when the gaskets were installed. In addition, the gaskets forced the insects to enter at predictable locations that could be targeted for increased pest management. These results will assist warehouse managers and pest management professionals with insect management plans.

8. Nematodes That Attack Insects Decreased Populations of Red Flour Beetles and Indianmeal Moths. Nematodes are the most numerous multi-celled animals on earth. Many of these microscopic creatures are parasites of insects (referred to entomopathogenic nematodes) and have potential as possible insect control tools.

Stored-product insects in hidden and difficult to access areas inside and outside food facilities can lead to infestation problems for both bulk grain and processed grain facilities. Entomopathogenic nematodes have been shown to be effective at finding and killing insect pests in cryptic locations, but their effectiveness against stored-product insects has not been previously investigated.

Members of the species *Steinernema riobrave* were found to be the most effective of three evaluated species against the widest range of stored-product pest species and life stages. This species reduced red flour beetle and Indianmeal moth populations under simulated field conditions. These biological control agents may be developed into a new management tool for use in targeted situations.

9. Long-Term Population Trends of Stored-Product Insects at Flour Mills Reveal Impact of Management Tactics. There are limited data available on the long-term population trends of stored-product insects in food processing facilities or the impact of pest management tactics on pests in the field, but this information is critical for the development of integrated pest management programs. In collaboration with ARS scientists in Gainesville, FL, we monitored insect pests at two flour mills to evaluate 1) seasonal trends in pest populations inside and outside facilities; 2) pest species diversity; and 3) the impact of treatments such as fumigation with methyl bromide or sulfuryl fluoride, aerosol fogging, and chemical pesticide sprays on population dynamics. Seasonal variation in trap captures of different species were detected, but red flour beetle trap captures were impacted more by fumigation treatments than season. Rates of population increase after treatment were determined and are being used to estimate rates of population rebound after treatment. This information will be used in the development of population models of pests in the field and to evaluate the effectiveness of different management tools. Finally, it will be used to develop more effective integrated pest management programs for the food industry.

Goals for 2006, 2007, and 2008:

Specific tasks in 2006 will be to:

1. Determine relationship between grain infestation level and flour fragment counts from wheat infested with rice weevils.

2. Evaluate accuracy of digital X-ray analysis equipment for detecting internal-feeding insects in grain.

3. Analyze data on red flour beetle movement patterns on different types of landscape patterns.

4. Evaluate red flour beetle movement behavior in and around spillage patches.

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5. Conduct experiments on red flour beetle response to pheromone traps in experimental arenas.

6. Analyze pilot-scale warehouse data on red flour beetle population response to pesticide applications and the accuracy of pheromone trapping in detecting impact.

7. Population genetic analysis using molecular markers will be performed to determine the relationships among red flour beetles captured in pheromone traps within flour mills.

8. Continue monitoring studies at food facilities to investigate the movement and distribution of insects in food plants.

9. Conduct mark-recapture studies to assess dispersal of insects in food plants and warehouses.

10. Continue monitoring pest population levels and environmental conditions in food facilities.

11. Continue measuring emigration and spatial variation in treatment efficacy in food facilities.

12. Validate simulation model for *T. castaneum*.

13. Validate computer simulation model developed for simulating population dynamics of *Plodia interpunctella*.

14. Continue to sample steel bins of wheat to determine temporal and spatial patterns of psocids.

15. Analyze data from psocid sampling studies to begin to determine method for predicting population levels in grain bins.

16. Conduct lab studies on effects of temperature and moisture on psocid development rate and survivorship.

Specific tasks in 2007 will be to:

1. Analyze red flour beetle behavior in spillage data and draft and submit paper on results.

2. Conduct warehouse beetle movement experiments.

3. Analyze red flour beetle response to traps in experimental boxes.

4. Complete DNA extraction, PCR with microsatellite primers, and analyze data to determine the degree of relatedness among red flour beetle populations.

5. Continue monitoring studies at food facilities and analyze data.

6. Conduct mark-recapture studies to determine how insect distributions in food plants change before, during and after treatments.

7. Initiate DNA extraction and PCR with microsatellite primers on additional red flour beetles collected to determine the degree of relatedness among more distantly separated populations.

8. Continue monitoring pest population levels and environmental conditions in food facilities.

9. Continue measuring emigration and spatial

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variation in treatment efficacy in food facilities.

10. Conduct experiments on the influence of perimeter treatments on red flour beetle immigration and emigration.

11. Develop model for simulating population dynamics of *Trogoderma variabile*.

12. Refine how the models simulate the movement of insects within and outside of flour mills, and the effects of control treatments on movement and mortality.

13. Conduct simulation studies with the computer simulation models to determine optimal management strategies.

14. Continue to sample steel bins of wheat to determine temporal and spatial patterns of psocids.

15. Investigate the relationship between psocid density in grain and subsequent fragment counts in flour.

Specific tasks in 2008 will be to:

1. Analyze warehouse beetle movement data and prepare paper.

2. Conduct warehouse beetle response to traps in experimental boxes.

3. Prepare recommendations on red flour beetle pheromone trapping and interpretation.

4. Conduct source identification experiments with red flour beetle.

5. Conclude monitoring studies at food facilities and analyze field efficacy and rate of rebound.

6. Conclude mark-recapture studies to assess dispersal.

7. Complete DNA extraction and PCR with microsatellite primers and analyze data to determine the degree of relatedness between red flour beetle populations.

8. Analyze the data on pest resurgence following treatment.

9. Continue measuring emigration and spatial variation in treatment efficacy in food facilities.

10. Validate the *Trogoderma variabile* simulation model and collect data to refine this model.

11. Continue to refine the simulation models to include other factors needed to accurately describe pest population dynamics.

12. Adapt the simulation models for warehouse environments.

13. Conduct simulation studies with the models to determine optimal management strategies.

14. Analyze data from study to determine the relationship between psocid density in grain and subsequent fragment counts in flour.

Specific Cooperative Agreements for This Project Included:

a. The Department of Electrical and Computer Engineering, Kansas State University, Manhattan, Kansas

b. The Department of Entomology, Oklahoma State University, Stillwater, Oklahoma

c. The Department of Grain Science and Industry, Kansas State University, Manhattan, Kansas

d. The Department of Entomology, Kansas State University, Manhattan, Kansas

e. The Department of Agricultural & Biochemical Engineering, Purdue University, West Lafayette, Indiana

f. The Department of Entomology, Montana State University, Bozeman, Montana

Summary of 2005 Publications/Patents:

1. Campbell, J.F. Fitness consequences of multiple mating on female *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae). 2005. Environmental Entomology v. 34. p 833-843.

2. Campbell, J.F., Arthur, F.H., Mullen, M.A. Insect management in food processing facilities. 2005. Advances in Food and Nutrition Research. v. 48. p. 240-295.

3. Mahroof, R., Subramanyam, B., Flinn, P.W. Reproductive performance of *Tribolium castaneum* (Herbst)(Coleoptera: Tenebrionidae) exposed to the minimum heat treatment temperature as pupae and adults. 2005. Journal of Economic Entomology v. 98. p. 626-633.

4. Qureshi, J.A., Buschman, L.L., Throne, J.E., Ramaswamy, S.B. Adult dispersal of *Ostrinia nubilalis* Hübner (Lepidoptera: Crambidae) and its implications for resistance management in Bt-maize. 2005. Journal of Applied Entomology. v. 129. p. 281-292.

5. Rintoul, D.A., Krueger, L.M., Woodard, C., Throne, J.E. Carrion beetles (Coleoptera: Silphidae) of the Konza Prairie Biological Station. 2005. Journal of the Kansas Entomological Society v. 78. p. 124-133.

6. Rodriguez-del-Bosque, L.A., Silvestre, F., Hernandez, V.M., Quiroz, H., Throne, J.E. Pathogenicity of *Metarhizium anisopliae* and *Beauveria bassiana* against *Phyllophaga crinita* and *Anomala flavipennis* (Coleoptera: Scarabaeidae). 2005. Journal of Entomological Science v. 40. p. 67-73.

7. Throne, J.E., Lord, J.C. Control of sawtoothed grain beetles (Coleoptera: Silvanidae) in stored oats using by using an entomopathogenic fungus in conjunction with seed resistance. 2004. Journal of Economic Entomology v. 97. p. 1765-1771.

8. Toews, M.D., Arthur, F.H., Campbell, J.F. Role of food and structural complexity on capture of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) in simulated warehouses. 2005. Environmental Entomology v. 34. p. 164-169.

9. Toews, M. D., Campbell, J.F., Arthur, F.H., West, M. Monitoring *Tribolium castaneum* (Herbst)(Coleoptera: Tenebrionidae) in pilot scale warehouses treated with residual applications of (S) hydroprene and cyfluthrin. 2005. Journal of Economic Entomology v. 98. p. 1391-1398.

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ENGINEERING RESEARCH UNIT

The mission of the Engineering Research Unit is to: (1) develop technologies to improve grain quality assessment, handling, and storage through innovative engineering research; (2) transfer knowledge and technology that meet the needs of consumers and the grain industry; (3) provide engineering expertise through cooperative research with other laboratories, agencies, universities, and industry groups; and (4) maintain an environment that fosters teamwork, innovation, and personal growth. Specific projects for this Unit include:

CRIS - 5430-43440-005-00D	Improved Handling and Storage Systems for Grain Quality Maintenance and Measurement
CRIS - 5430-44000-015-00D	Objective Grading and End-Use Property Assessment of Single Kernels and Bulk Grain Samples

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CRIS 5430-43440-005-00D

Improved Handling and Storage Systems for Grain Quality Maintenance and Measurement

Project Leader: M. Casada

Investigators: M. Casada, P. Armstrong, and F. Dowell

Full-Time Scientist Equivalents (SYs): 1.7

Start Date: 09/01/04

Term Date: 08/31/09

Problem: Worldwide grain markets are changing and customers are now demanding grain that meets their specific needs for end-use properties and that is purer, safer, and more wholesome. They are demanding grain with fewer insects, diseases, and pesticides and either no genetically modified (GM) grain or strictly controlled levels of GM grain.

The introduction of transgenic crops into the U.S. grain handling system has shown that the infrastructure is largely unable to preserve the identity of specialty grains to the desired level of purity. Fundamental data are needed on commingling during handling, along with methods to minimize or eliminate this problem to effectively separate grains with special desirable characteristics, which adds value compared to commodity grains. A survey of our industry focus group showed strong support for this study of identity preservation of grain.

Existing packing factor data are of unknown reliability and are widely mistrusted in the industry. Accurate data are required for government-mandated inventory control and are a crucial component of new quality management systems being developed to enable source verification in the grain handling industry. The Farm Service Agency (FSA) is not able to do a thorough review and, as a result, along with the Association of American Warehouse Control Officials (AAWCO) has asked ARS to evaluate their existing packing factor data.

Aeration is an underused tool for controlling insects and other risks in stored grain without the use of chemical pesticides, particularly in small grains in warm climates. This significant omission may lead to continued losses of 5 to 10% in stored grain in some U.S. climates. Appropriate control strategies and improved monitoring systems are needed so that aeration will be more widely used to reduce pesticide treatment of stored grain. Since pesticides also are used to sanitize bins before storage, a chemical-free method for sanitizing grain storage bins before filling also is needed. Our industry focus group survey showed strong support for studies of stored grain insect control, and especially strong support for these entirely chemical-free methods.

Grain dust has adverse health effects and can lead to explosion disasters such as the 121 reported agricultural dust explosions between 1993 and 2002 that killed 16 people, injured 149, and caused over $100 million of facility damage. Improved system design procedures are needed for grain dust collection systems. Data also are needed on dust composition, levels of emission, and particle size distribution during grain unloading as affected by type of grain, moisture content, grain quality, grain flow rate, and drop height.

Objectives: The specific objectives of this research are: 1) Measure grain commingling levels during elevator handling for use in developing procedures, decision support systems, and instrumentation to facilitate value-added and identity-preserved grain segregation operations; 2) Develop new stored grain packing factors with known accuracy as needed for common grains in trade over a range of field conditions; 3) Develop improved aeration, monitoring, and sanitation systems and best management practices for quality maintenance and insect control in stored grain; and 4) Measure dust emission, particle-size distribution, and air entrainment during grain unloading to facilitate reducing dust emissions from grain handling operations and equipment.

Results and Impact:

1. Value-Added Grain Can Be Segregated at a Country Elevator With Only One Dump Pit. This study measured the level of commingling of soybeans in corn when both grains are received at a country elevator using only one dump pit. In this study, more than one mechanism was used to move the grain from the bottom of the dump pit to the elevator leg. Commingling exceeded 1% only during the first 75 to 135 seconds (40 to 80 bu of grain received). Measured mean cumulative commingling was 0.30% for the combined effect of leg and pit with drag conveyor, and 0.23% for the bucket elevator alone. A simulation model based on this data predicted that a facility equipped with a bucket elevator and receiving pit with drag conveyor receiving 10 tons of grain would yield a final commingling of at least 0.28%, of which 0.27% would be from the effect of the leg. With minimum cleaning between loads, a load of grain handled immediately after a load of a different grain type would generate the highest amount of commingling. This information is needed by elevator operators to better segregate grain with desirable characteristics into separate channels for delivery to end-users. The information is also useful to grain processors for improving their handling of specialty grains.

2. A High-Pressure Water-Fogging System for Grain Dust Control. Grain dust is a health risk to workers and a fire risk for facilities. Several dust control methods are available such as a pneumatic system and suppression with edible oils. A high-pressure fogging system was tested for potential as a dust control method. The drop size and induced airflow characteristic of the high-pressure fog were identified. Airflow and particle trajectory mathematical models were calculated for typical grain receiving and for fog treatment at grain receiving. The mathematical models predicted air recirculation into the receiving hopper when the spray system was operated. Smoke tests were used to validate the air flow models. The fogging system improved dust containment as demonstrated by the air and particle trajectory models. Fog emissions and deposits were generated and were small and manageable, but they could become a problem if mismanaged. The use of a spray-fog system for grain dust control would need approval from regulatory agencies and is currently restricted by U.S. laws protecting the quality of grain shipments.

3. Wireless Data Transmission May Help Maintain Grain Quality. During grain storage, the quality of grain can deteriorate due to the presence of high grain moisture and insects. In both instances, grain temperature is a good indication when these adverse conditions are present. Most large grain storage facilities use elaborate grain temperature monitoring systems, which require multiple temperature sensors wired to a central computer. Smaller storage facilities do not usually have these systems due to their cost or because the storage is only used for short periods.

Wireless sensors, which use radio waves to transmit temperature data, may provide a more convenient way to measure grain storage temperature in some cases. They can be used for temporary storage or be permanently fixed in the larger storage structures as an alternative to wired sensors. Wireless sensors also have the potential to travel with the grain during distribution.

Radio transmitter receiving signals from sensors in grain bin.

A limiting factor for wireless data transmission is the ability to transmit radio waves through grain with a small, low-power, battery operated device. Tests were conducted with a commercial wireless sensor development system to determine transmission range. These particular wireless sensors were about 2 x 0.5 x 1.5 inches in size. Results showed that data could be transmitted through grain over a two-meter distance at power levels that would allow about three years of operation. This is roughly the distance between adjacent wired sensors in commercial storage. The ability of these sensors to communicate with each other in a "sensor network" allows them to relay data from sensor to sensor and extend the range of transmission infinitely. As a result, wireless sensors have the potential to improve the overall grain storage infrastructure by providing a system that can be used to monitor storage facilities, which would otherwise not be economically practical.

4. How Much Breakage Occurs in Handling Non-Grain Items Like Feed Pellets? The objective of this research is to determine the durability of feed pellets in normal handling and compare to similar measures of durability of yellow corn. The durability tests were conducted in accordance with ASAE S269.4 DEC 01. The pellet breakage tests were conducted using the grain handling system at GMPRC in accordance with procedures similar to those in previous studies with at GMPRC with corn where appropriate.

Preliminary results showed that the apparent geometric mean diameter (GMD) of feed pellets decreased while the mass of accumulated broken pellets increased with repeated transfers. The initial value of 17.5% breakage increased by an average of 3.8% with each transfer during eight transfers. Average percent breakage was within the range of published values for shelled corn obtained from the same elevator. The measured pellet durability index (PDI) averaged 93% and did not change significantly during the transfers. The high pellet durability index indicated that the pellets can withstand repeated transfers in feed handling systems.

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Goals for 2006, 2007, and 2008:

Specific tasks in 2006 will be to:

1. Obtain operational mixing data for second commercial elevator; finish and evaluate initial expert system and recommendations.

2. Continue wheat data and begin calibrating model; publicize results to potential funding sources.

3. (a) Second year of field trials; develop simple physical models; (b) complete gas-fired heater tests, begin tests with large portable electric heater; (c) develop sensor networking and interfacing; data collection and analysis on small scale storage; and (d) evaluate data and develop procedures for effective insect monitoring.

4. Complete entrainment data, continue dust emissions, and begin model development.

Specific tasks in 2007 will be to:

1. Finalize basic procedures and recommendations for IP handling operations; obtain additional data.

2. Complete initial wheat data and model calibration for wheat; seek additional funds based on these wheat results.

3. (a) Third year of field trials; complete simple physical model; (b) complete data analysis and economic model, evaluate additional research needs; (c) data collection on performance and reliability of wireless sensors, develop model and use guidelines; and (d) examine signal analysis of insect monitor and implement improvements.

4. Complete dust emission data and continue model development.

Specific tasks in 2008 will be to:

1. Begin revision of expert system; obtain additional data; evaluate specific equipment for design improvements.

2. Begin data collection for second grain type; continue seeking funds, or begin large project if funds in place.

3. (a) Begin complete physical model; evaluate further field trials; (b) none in this FY; (c) design practical sensors for RH/Temp monitoring, test large scale storage applications; and (d) determine improvements in monitoring based on storage tests.

4. Complete model refinement, evaluate need for more data and dust control methodologies.

Cooperative Research and Development Agreements for This Project Included:

a. The Grain Industry Alliance, Manhattan, KS

Trust Agreements for This Project Included:

a. Agsense LLC, Huron, SD

Summary of 2005 Publications/Patents:

1. Akdogan, H.P., Casada, M., Dowdy, A., Subramanyam, B. A novel method for analyzing grain facility heat treatment data. 2005. Journal of Stored Products Research. 2005. v. 41. p. 175-185.

2. Brabec, D.L., Maghirang, R.G., Casada, M., Haque, E. Characterization and modeling of a high-pressure water-fogging system for grain dust control. 2005. Transactions of the ASAE. v. 48. p. 331-339.

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CRIS 5430-44000-015-00D

Objective Grading and End-Use Property Assessment of Single Kernels and Bulk Grain Samples

Project Leader: T. Pearson

Investigators: T. Pearson, F. Dowell, and P. Armstrong

Full-Time Scientist Equivalents (SYs): 2.3

Start Date: 09/01/04

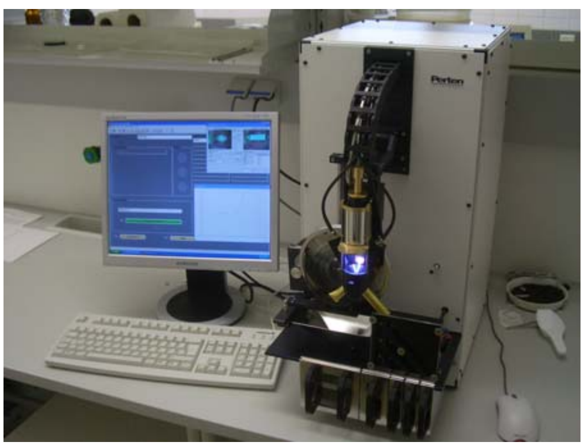
Term Date: 08/31/09

Problem: The U.S. is a major consumer and exporter of cereal grains. However, for the U.S. grain industry to remain competitive internationally and to meet domestic consumer demands for quality, it must continually improve the quality of grain and grain products. We propose to address three important problems that the U.S. grain industry faces in order to improve end-use quality of grain: 1) Grain properties that have the most influence on final or end-use product quality are not well known. For example, we do not know how most wheat kernel properties affect bread quality. This makes selection of grain difficult for buyers, and it is difficult for breeders to know what traits should be propagated; 2) Many instruments designed to detect the quality of whole grains suffer from poor accuracy, high cost, being too slow, requiring toxic chemicals, or do not directly measure the end-use qualities that customers need to know; and 3) In many cases, economically viable instruments do not exist to measure and/or sort whole grain defects that occur in small fractions of grain but can have a deleterious effect on quality, such as insect-damaged wheat kernels or mold damaged grain.

Objectives: The primary goal of our research is to improve the quality and safety of grain and grain products through the development of instrumentation and procedures for objective grading and on-line quality measurement and sorting, and correlation of single-kernel and bulk-sample grain properties to end-use quality measurements. Specific objectives, or milestones, are to: 1) Develop automated, rapid-sensing and sorting technology for single kernels. Systems will be developed to a) detect wheat kernel defects using acoustics, and b) detect characteristics of single corn kernels by automating the acquisition of a plurality of measurements including imaging, weight, and near-infrared spectra; 2) Measure characteristics of single kernels and bulk samples that are critical to the success of the grain industry by utilizing experimental or commercial instrumentation. This includes a) detecting and removing kernels with mycotoxin-producing molds, b) detecting mutants for corn breeders, c) measuring oat milling parameters, and d) detecting insect fragments in flour; and 3) Develop techniques, using single and multiple measurements, to predict end-use characteristics such as flour yield, bake absorption, farinograph stability, loaf volume, etc., from whole grain or minimally processed grain, and to determine the accuracy and impact of these predictions. This includes studying the synergy of combining multiple measurements.

Results and Impact:

1. Automated NIR Sorting Technology Commercialized. The single kernel sorting system developed to detect specific grain attributes was commercialized through a CRADA with Perten Instruments, Stockholm, Sweden. The system was demonstrated at several international conferences in 2005 and is being publicly marketed. It automatically scans individual wheat kernels, and then sorts kernels based on specific attributes such as protein content, hardness, amylose content, etc. The system is now being used by breeders to select specific traits from early generation breeder samples. This will significantly reduce the time and expense required to develop cultivars with specific end-use traits. The system is also being evaluated for use in detecting food safety attributes such as vomitoxin during routine grading. Although it was developed for wheat, it is also finding applications in sorghum and millet.



Commercial single kernel NIR system for selecting kernels with specific attributes.

2. Rapid Sorting Improves the Quality of White Wheat Being Developed in Breeding Programs. White wheat is gaining acceptance throughout the Midwest as a class that can improve our competitiveness in export markets. All breeding programs in the Midwest are developing white wheat cultivars. We are able to improve the quality of white wheat cultivars being used in breeding programs by removing wheat of other classes, such as red wheat, from samples using high speed sorting procedures developed through a memorandum of understanding (MOU) with Satake, Inc. There is no other technology available to remove these contaminating kernels.

Almost all white wheat being developed in the Midwest and Pacific Northwest is now shipped to our research unit for purification through our sorter. Our sorting has reduced the development time for these new cultivars by several years, has saved the breeders hundreds of hours, and has salvaged some cultivars that would have been terminated if this technology was not available. The first commercial wheat variety that had been sorted using this technology named “Bullet” was released by Oklahoma State University this year.

High speed sorting system for purifying large samples for breeding programs.

3. Wheat Kernel Defects Detected Using Sound on Impact. We have built a system that is able to distinguish good wheat kernels from a variety of damaged kernels by dropping kernels, one at a time, onto a steel plate and digitally analyzing the resulting sounds from the impact. The types of damage studied were insect damaged kernels with exit holes, hidden insect damaged kernels without exit holes, sprout damage, and scab damage.

We found that 98% of the good kernels and 87% of the insect damaged kernels with exit tunnels can be distinguished from each other. Accuracy for scab and sprout damaged kernels was 70% and hidden insect damaged kernels were detected with an accuracy of 45%.

The device should be capable of inspection rates exceeding 40 kernels per second, or approximately 70 g of wheat per minute. The process is non-destructive and can be made to sort kernels into one of three different groups. This technology should help grain inspectors and millers better ascertain the quality of a wheat load under consideration.

Goals for 2006, 2007, and 2008:

Specific tasks in 2006 will be to:

1. Detect wheat kernel defects using single kernel acoustics from impact emissions. Develop working prototype that works in real time.

2. Detect characteristics of single corn kernels using NIR spectroscopy. Develop sorting system.

3. Detect and remove kernels with mycotoxin-producing molds. Test sorter; chemically analyze sorter accepts and rejects for mycotoxins.

4. Detect mutants for corn breeders. Analyze data to detect mutants; develop clustering procedure of different mutant classes.

5. Detect single-kernel oat milling parameters. Develop SKCS groat-damage prediction.

6. Detect insect fragments in flour. Development of fragment- detection algorithms.

7. Predict end-use quality. Develop prediction models for HRW and HRS wheat.

Specific tasks in 2007 will be to:

1. Detect wheat kernel defects using single kernel acoustics from impact emissions. Test prototype with field samples, including mold damaged, broken kernels, germinated and kernels damaged by insects that are external feeders.

2. Detect characteristics of single corn kernels using NIR spectroscopy. Develop calibrations.

3. Detect and remove kernels with mycotoxin-producing molds. Verify sorter performance with more samples.

4. Detect mutants for corn breeders. Measure chemical constituents in groups of mutants and normal kernels.

5. Detect single-kernel oat milling parameters. Develop SKCS groat size, oat-fill rate measurement.

6. Detect insect fragments in flour. Develop a prototype instrument for research/industrial lab.

7. Predict end-use quality. Verify models with field data. Begin studying other classes.

Specific tasks in 2008 will be to:

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1. Detect wheat kernel defects using single kernel acoustics from impact emissions. Test prototype with field samples, including mold damaged, broken kernels, germinated and kernels damaged by insects that are external feeders.

2. Detect characteristics of single corn kernels using NIR spectroscopy. Begin development of commercial prototypes.

3. Detect and remove kernels with mycotoxin-producing molds. Transfer technology to industry.

4. Detect mutants for corn breeders. Modify models as needed.

5. Detect single-kernel oat milling parameters. Incorporate measurement criteria into a commercial SKCS.

6. Detect insect fragments in flour. Compare imaging and human inspection. Redesign as needed.

7. Predict end-use quality. Modify models as needed.

Specific Cooperative Agreements for This Project Included:

a. JAG Services, Inc., Manhattan, KS

Cooperative Research and Development Agreements for This Project Included:

a. Perten Instruments, NA, Springfield, IL

Reimbursable Agreements for this Project Included:

a. Florida State University, Horticulture Sciences Department, Tallahassee, FL

Memorandums of Understanding for This Project Included:

a. Satake, Houston, TX

Summary of 2005 Publications/Patents:

1. Dowell, F.E., Parker, A.G., Benedict, M.Q., Robinson, A.S., Broce, A.B., Wirtz, R.A. Sex separation of tsetse fly pupae using near-infrared spectroscopy. 2005. Bulletin of Entomological Research v. 95. p. 249-257.

2. Wang, N., Zhang, N., Dowell, F.E., Pearson, T.C. Determining vitreousness of durum wheat using transmitted and reflected images. 2005. Transactions of the ASAE. v. 48. p. 219-222.

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GRAIN QUALITY AND STRUCTURE RESEARCH UNIT

The mission of the Grain Quality and Structure Research Unit, which includes the Hard Winter Wheat Quality Laboratory, is to ensure a high quality and safe U.S. grain supply for our customers by: (1) conducting basic and applied research to identify the physical characteristics and structural/biochemical components that govern quality; (2) developing rapid, precise, and accurate predictive technologies for quality assessment; and (3) evaluating the end-use quality of breeding lines. Specific projects for this Unit include:

CRIS - 5430-44000-016-00D	Characterization of Grain Biochemical Components Responsible for End-Use Quality
CRIS - 5430-44000-017-00D	Enhanced End-Use Quality and Utilization of Sorghum Grain
CRIS - 5430-44000-018-00D	Enhancement of Hard Winter Wheat Quality and Its Utility (Hard Winter Wheat Quality Laboratory)

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CRIS 5430-44000-016-00D

Characterization of Grain Biochemical Components Responsible for End-Use Quality

Project Leader: M. Tilley

Investigators: M. Tilley and J. Wilson

Full-Time Scientist Equivalents (SYs): 1.5

Start Date: 10/01/04

Term Date: 09/30/09

Problem: The baking industry encounters tremendous loss in the areas of quality assurance to customers, consistency of product, processing parameters and product waste. It is estimated that as much as 10% of a company's product is relegated to waste due to lack of flour consistency. This variability in composition and quality of wheat flour is dependent upon genetic, environmental, and supply chain factors. For example, not only will the protein content vary from lot to lot, but within a given protein content range (usually specified by end user requirements), the quality of the protein will vary considerably. Even when basic product specifications, such as ash, moisture, and protein content are met, the dough forming and baking characteristics of a given lot of flour are highly unpredictable.

Similarly, ingredient and processing variability translates into large economic losses in the baking industry. The U.S. baking industry annually uses about 42 billion pounds of flour, valued at about $4.2 billion, to produce an estimated $33 billion of baked goods. Variability in flour quality means that there are opportunities for large savings in the areas of raw material selection, processing, and distribution. Further, improved methodologies to better analyze the root causes of flour variability will open the door to the production of higher value products.

The baking industry has limited tools at its disposal to deal effectively with the variability of wheat flour, its major raw material. All the tools currently utilized by industry for assaying and/or testing flour are highly empirical, offering little insight into the biochemical basis of (a) what constitutes a "quality" flour, (b) how a particular lot of flour can be characterized for its suitability for a given application, or (c) how a particular lot of flour should be processed to maximize product quality.

Objectives: The objectives of this project are to: (1) Determine the roles and interactions of the major biochemical components of cereal grains (starch, storage proteins and enzymes) as they relate to food quality and functionality; (2) Define the role of the environment on functional properties of biochemical components that affect end-use properties; and (3) Use the information generated in previous objectives to develop and refine methods to rapidly predict grain quality.

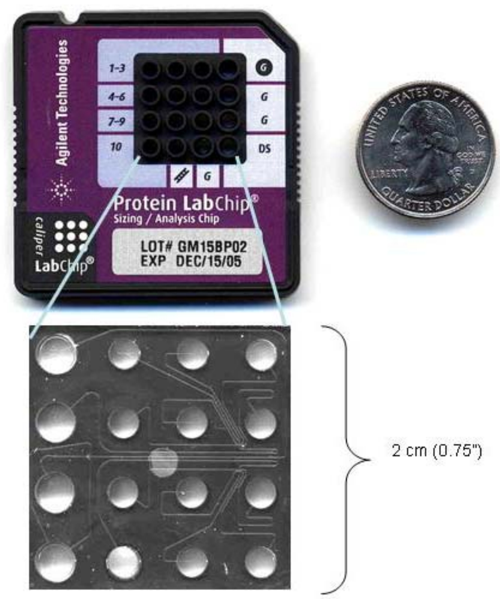
In meeting these objectives, we will investigate the role of wheat starch granule size distributions on variations in functionality during bread-making. Various starch fractions containing different sizes of granules will be used for reconstitution experiments to determine how size classes affect breadmaking quality. Oxidative enzymes will be added to wheat flour to determine the chemical effects on storage proteins and non-storage proteins. Protein fractions and polymers will be examined using a variety of analytical techniques before and after the addition of oxidative enzymes.

Environmental impacts on both starch and storage proteins will be determined using samples that have been exposed to controlled temperature and irrigation regimes during development. The potential of novel microfluidic devices will be thoroughly examined. These devices called “lab-on-a-chip” represent new advances in analytical techniques and provide a means to generate extremely rapid and highly reproducible separations of proteins for grain cultivar identification and quality prediction.

Advances in the knowledge of grain biochemical characteristics that determine the physical and functional properties critical to processing and end-product quality, and development of rapid, accurate methods to measure these quality determinants are essential to maintain a competitive position for U.S. grain in global markets. This project will provide the cereal food industry with the tools needed to define the end-use performance of cereal grains.

Results and Impact:

1. Microfluidics System Tested as Potential Wheat Cultivar Identification and Quality Prediction Tool. Knowledge of cereal proteins is important both for predicting flour end-use performance and for varietal identification. Microfluidic systems (called “lab-on-a-chip”) produce fast separations using very small liquid volumes. We have purchased an Agilent 2100 microfluidics instrument that utilizes a small chip (see picture below) resulting in rapid size-based separation of proteins in less than one minute after a 5-second extraction from the kernel.



Microfluidics “lab-on-a-chip.”

We are collaborating with the Grain Inspection Packers and Stockyards Administration (Federal Grain Inspection Service) (GIPSA-FGIS) to determine the suitability of this technology for discriminating wheat cultivars by comparing wheat protein separation patterns to those obtained from cultivars using HPLC-based standard methods. Sample analysis by HPLC typically requires 30 to 40 minutes each, thus microfluidics methods have potential for significantly shortening the analysis time with the added advantage of portability. More research is being conducted to evaluate this new system on the GIPSA-FGIS library of over 500 wheat varieties.

In the future, we will develop this technology to characterize polymeric proteins in order to predict mixing strength and other flour quality parameters.

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2. Treatment of Flour with Glucose Oxidase Changes Proteins. Chemical oxidants are routinely added to flour to modify dough properties (shorten mixing time, improve gas retention, lower energy requirements for dough mixing, etc.) and enhance breadbaking performance (increase loaf volume and improve crumb structure). The elimination of potassium bromate, and possibly other chemical oxidant additives, presents a challenge to the baking industry. Oxidoreduction enzymes such as glucose oxidase have been proposed as alternative improvers. We generated wheat flour dough with and without the presence of glucose oxidase and the different classes of proteins were extracted and analyzed. The most significant effects were observed to occur in the albumin (water soluble) and gliadin (alcohol soluble) protein groups. A significant increase in protein concentration and molecular weight distribution was observed in the albumin fraction. Additionally, the enzyme addition increased gluten polymer size due to protein crosslinking. Using glucose as a substrate, glucose oxidase forms hydrogen peroxide which is a highly reactive oxidizer that can either be active on its own or that can serve as a substrate for another oxidative enzyme called peroxidase. Studies are now concentrated on dissecting the role of added glucose oxidase on the native wheat peroxidase enzyme. This information will be useful in manipulating the polymer sizes produced during dough formation in order to improve the consistency of wheat flour.

3. Starch Size Distribution Impacts Baking Quality and May Be Impacted by the Environment. Starch constitutes the largest weight portion (approximately 75%) of wheat endosperm and it contributes its own unique functional qualities such as volume, texture, appearance, and staling rate to food made from wheat flour. Varying ratios of large (type-A) and small (type-B) granules have been proposed to change the baking potential of bread. Bread made from reconstituted flour with 30% type-B to 70% type-A ratios gave optimum crumb grain scores and peak fineness values and second highest elongation ratios. However, as the proportion of type-B granules increased, the bread that was produced contained a softer texture and maintained that texture better during storage.

In order to determine the impact of the environment on the distribution of starch granules, we have begun to compare weather conditions (temperature and precipitation) to starch size distribution in developing wheat. At present, seven years of isolated starch is being analyzed via laser diffraction sizing and all pertinent weather data has been incorporated into the database. With samples collected over multiple years it will be possible to trace the impact of changes in environmental growing conditions to critical growing phases in starch development. This may be useful in developing a data base incorporating environmental information during the growing season to ideal starch development for optimum end-use quality.

Goals for 2006, 2007, and 2008:

Specific tasks in 2006 will be to:

1. Continue to determine the role of individual starch granule populations by isolating large quantities of starch and separating it into size fractions for baking and chemical testing.

2. Continue to test the correction model for starch size distributions by laser diffraction sizing (LDS). This will evaluate the correction to determine if each class of wheat should

have its own correction factor or if all classes of wheat can use the same factor.

3. Determine the effects of oxidative enzymes and transglutaminase upon quality characteristics.

4. Conduct biochemical analysis on the effects of enzymes on protein interactions.

5. Use LDS and our correction model to detect environmental differences in starch ratios. We will continue isolating the starch fractions from different environments for chemical analysis.

6. Acquire representative samples for "Lab-on-a-chip" analysis to develop a library of protein profiles of commonly grown U.S. wheat cultivars.

Specific tasks in 2007 will be to:

1. Continue to isolate large quantities of starch, separated into size fractions for baking and chemical testing.

2. Continue to test the correction model for starch size distributions by laser diffraction sizing (LDS).

3. Continue to characterize enzyme effects on protein interactions. We will determine the contribution of individual glutenin subunits on enzyme mediated crosslinking in gluten functionality.

4. Compare starch size distributions and chemical analysis to different environments and determine if particular proteins/starch granule ratios are markers for quality traits.

5. Test unknown and difficult to classify samples of wheat against the protein fingerprint library developed.

6. Improve extraction methodologies and separation techniques incorporating novel methods available at that time.

Specific tasks in 2008 will be to:

1. Conduct bake studies using reconstituted gluten and starch fractions.

2. Begin testing amylose/amylopectin ratios, pasting profiles, differential scanning calorimetry (DSC) temperatures and lipids of A, B, and C-type starch fractions on baking quality.

3. Perform chemical analyses of the starch fractions and correlate the results with bake data and starch size distributions.

4. Determine the contribution of individual glutenin subunits on enzyme-mediated cross linking in gluten functionality.

5. Complete the chemical analyses of starch.

6. Compare starch size distributions and chemical analyses to different environments.

7. Relate polymer sizes and molecular weight distributions to quality characteristics, provided by the HWWQL.

8. Develop Lab-on-a-chip to identify quality-related proteins and unique proteins associated with specialty wheat.

9. Continue to analyze the effects of environment on protein content and quality.

Summary of 2005 Publications/Patents:

1. Bechtel, D.B., Wilson, J.D. Endosperm structural changes in wheat during drying of

maturing caryopses. 2005. Cereal Chemistry. v. 82. p. 385-389.

2. Park, S., Chung, O.K., Seib, P.A. Effects of varying weight ratios of large and small wheat starch granules on experimental straight dough bread. 2005. Cereal Chemistry. v. 82. p. 166-172.

3. Park, S., Chung, O.K., Seib, P.A. Size distribution and properties of wheat starch granules in relation to crumb grain score of pup-loaf bread. 2004. Cereal Chemistry. v. 81. p. 699-704.
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CRIS 5430-44000-017-00D

Enhanced End-Use Quality and Utilization of Sorghum Grain

Project Leader: S. Bean

Investigators: S. Bean, L. Seitz, and M. Tilley

Full-Time Scientist Equivalents (SYs): 2.5

Start Date: 10/01/04

Term Date: 09/30/09

Problem: In recent years, U.S. sorghum production has declined. Sorghum is a low input, drought-tolerant crop grown in several parts of the U.S. and around the world. Sorghum is used primarily as animal feed in the U.S. (second only to maize), although ~30 to 40% of worldwide production is used as human food. In 1998, the U.S. produced ~20% of the worldwide sorghum supply. Annually, ~30 to 50% of the U.S. sorghum crop is exported. Therefore, new uses for sorghum could represent new markets for U.S. agriculture. In addition, the drought-tolerance of sorghum makes it attractive for future growth in areas of low water availability. Increased utilization of sorghum could serve as a tool for rural renewal in areas where sorghum is a major crop and where water is limited for production of other crops such as maize and soybeans.

Sorghum has potential for several uses including a source of renewable bioindustrial products such as ethanol, lactic acid, and biodegradable films and packaging. Sorghum also represents a safe food for people who cannot eat wheat. However, several obstacles must be overcome in order to increase the utilization of sorghum. While some research directed at using sorghum in food products and industrial products (such as biodegradable films) has been carried out, comparatively little research has been conducted on the relationship between sorghum biochemistry and end-use quality and utilization.

Objectives: This project will focus on the relationships between sorghum biomolecules and end-use quality and utilization of sorghum.
Specific objectives of this research are to: (1) Develop a better understanding of the role of sorghum proteins in digestibility in order to increase the nutritional quality of sorghum; (2) Develop a better understanding of the role of proteins, starch, and lipids in the functionality of sorghum in sorghum foods; (3) Identify key components that are important to functionality; (4) Develop rapid and reliable methods for measuring key components to assist in predicting quality; and (5) Investigate the potential for modifying sorghum to improve the functionality and nutritional quality of sorghum.

Results and Impact:

1. Color Compounds in Sorghum Identified and Related to Weathering. Weathering and molding of sorghum grain can lower the end-use quality by producing discoloration and off odors. This is especially important in white sorghums used to produce flour for food products. We analyzed the concentrations of six 3-deoxyanthocyanidins (apigeninidin, luteolinidin, plus their 5-O- and 7-O-methyl derivatives) and two flavones (apigenin and

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luteolin) in samples of sorghum grain and glumes from purple- and tan-plant hybrids with varying degrees of moldiness (see picture below). In grain from purple plants, concentrations of certain 3-deoxyanthocyanidins were high in samples with high ergosterol content, indicating that mold invasion greatly enhanced production of these compounds.

Sorghum harvested from purple plants showing normal seeds (left) versus mold damaged seeds (right).

Concentrations of 3-deoxyanthocyanidins in grain and glumes from purple plants were generally much higher than those from tan plants. Compared to grain, glumes had high degree of moldiness, high concentrations of 3-deoxyanthocyanidins or flavones, and different relative amounts of compounds. Because grain and glumes from the same hybrid had different relative concentrations among the six 3-deoxyanthocyanidins, it appeared that the compounds were produced in the grain and glume tissues where damage occurred as opposed to being transferred from one location to another such as from glumes to grain during exposure to precipitation. Ergosterol and 3-deoxyanthocyanidin levels were high in bran, which was consistent with highest mold levels usually occurring in the outer portion of the seed. This research provides information on the role of color compounds in the weathering of sorghum hybrids. It is especially important in white sorghums, where weathering causes off colors and flavors. Understanding the role of color compounds should help in the development of improved white sorghum lines, which would benefit sorghum producers, the sorghum food industry, and persons with celiac disease.

2. Decortication Increased Ethanol Production. Decortication involves removal of the outer layer (bran) of the sorghum kernel. The bran is primarily made of fiber, which is not broken down to sugars and fermented during the production of ethanol. We investigated the effect of decortication as a pretreatment method on ethanol production from sorghum as well as its impact on distiller's dry grains (DDGS). Eight sorghum hybrids with 0, 10, and 20% of their outer layer removed were used as raw materials for ethanol production. The decorticated samples were fermented to ethanol by using *Saccharomyces cerevisiae*. In general, decortication decreased the protein content of the samples up to 12% and increased starch content by 5 to 15%. Fiber content was decreased by 50 to 90%. These changes allowed for a higher starch loading for ethanol fermentation and resulted in increased ethanol production. Ethanol yields increased 3 to 11% for the 10% decorticated sorghum and 8 to 18% for the 20% decorticated sorghum. Using decorticated grain increased the protein content of DDGS by 11 to 39% and lowered fiber content 22 to 55%. Using decorticated sorghum may be beneficial for ethanol plants as ethanol yield increases and feeding quality of the DDGS is improved.

3. Phytochemicals from Grain Sorghum Improve Cholesterol Patterns in Hamsters. Grain sorghum is a rich source of phytochemicals that could potentially benefit human health. In our recent study, male hamsters were fed AIN-93M diets supplemented with a hexane-extractable lipid fraction from grain sorghum whole kernels. The grain sorghum lipids (GSL) comprised 0.0, 0.5, 1.0 or 5.0% of the diet by weight. After four weeks, dietary GSL significantly reduced plasma non-HDL cholesterol concentration in a dose-dependent manner with reductions of 18, 36 and 69% in hamsters fed 0.5, 1.0 and 5.0% GSL, respectively, compared to controls. Liver cholesteryl ester concentration was also significantly reduced in hamsters fed GSL. Plasma HDL cholesterol concentration was not altered by dietary treatment. Cholesterol absorption efficiency was significantly reduced by GSL in a dose-dependent manner and was strongly correlated with plasma non-HDL cholesterol concentration ($r = 0.97$, $P < 0.05$).

Thin-layer and gas-liquid chromatographic analysis of the GSL extract revealed the presence of plant sterols and policosanols at respective concentrations of 0.35 and 8.0 g/100 g GSL. While plant sterols are known to reduce cholesterol absorption, policosanols may inhibit endogenous cholesterol synthesis. The data suggested that the GSL extract may work collectively in lowering plasma and liver cholesterol concentrations. Our findings further indicate that grain sorghum contains beneficial components that could be used as food ingredients or dietary supplements to manage cholesterol levels in humans.

4. Sorghum Waxes Lower Cholesterol Levels. Evidence suggests that VLCFAs (very long chain fatty acids, aldehydes and alcohols containing from 24 to 30 carbon atoms) from plant waxes alter cholesterol metabolism (Hargrove et al., Exp. Biol. Med. 229:215-26, 2004). Wax from sorghum (*S. bicolor*) grain is enriched with non-esterified VLCFAs that are normal constituents of whole food diets. We have conducted an open-label clinical trial to evaluate whether consumption of sorghum wax would affect serum cholesterol. Twelve human subjects with elevated cholesterol levels, between the ages of 35 and 58, participated. Their initial body mass indexes (BMIs) ranged from 26-33 kg/m^2. Sorghum wax (provided as a gift by US Energy Partners, LLC, Russell, KS) was taken in 100 mg capsules 2X daily with meals for 60 days. This dose approximates the amount of wax in 1/3 cup of whole grain sorghum flour. Total serum cholesterol (TC), low density lipoprotein (LDL) and high density lipoprotein (HDL) cholesterol, lipid peroxides (LPs) and body weights were determined in blood samples obtained at 0, 30 and 60 days.

Significant decreases in TC, LDL, LDL/HDL, TC/HDL, LPs, body weight and body mass indices occurred over 60 days. HDL levels were unaltered and no adverse side effects were reported. Therefore, incorporation of sorghum wax into the diet may benefit blood lipid profiles and potentially affect weight maintenance. These effects may contribute to known beneficial effects of whole grains, vegetables and fruits on cholesterol profiles.

We also developed a Caco-2 cell culture model to determine the effects of sorghum proanthocyanidins (tannins) on the uptake and transport of cholesterol across the gut epithelium. This model allows us to screen for phytochemicals in nutritional supplements that have potential for lowering blood cholesterol levels. Sorghum tannins decreased cholesterol influx into the Caco-2 cells up to 80% when compared with controls.

5. Tannin Analysis and Antioxidants of Sorghum Differ with Origin. Tannin analysis of a large number of sorghum samples using the Vanillin-HCl acid method indicated that sorghums with a pigmented testa and spreader genes had the highest levels of condensed tannins while sorghums with a pigmented testa without a dominant spreader gene had low levels of condensed tannins and those sorghums without a pigmented testa had only trace amounts of condensed tannins. The pigmented testa is a layer in the sorghum kernel immediately under the bran in some sorghum lines. Tannins (proanthocyanidins) are deposited in this layer as the seed matures.

High Performance Liquid Chromatography (HPLC) indicated that there were no tannins in the extracts of sorghum grains without a pigmented testa. The total phenol content varied significantly but was higher when the pigmented testa was present. Wheat, corn, barley, oats, millet, rice and several other grains had significantly lower levels of phenols and antioxidants (in vitro) than sorghum. Some 130 sorghum varieties from West Africa were analyzed for the presence of a pigmented testa with the chlorox bleach method. Those with a pigmented testa were analyzed for tannins with the Vanillin-HCl method. The levels of condensed tannins varied from 2.6 mg to 26.7 mg C.E. per g while the condensed tannins in 8 tannin sorghum hybrids grown in the USA were much higher (16.6 to 56.3 mg C.E. per g) because they had dominant B1B2S genes. Therefore, the B1B2S genes significantly influence the tannin content and sorghum germplasm containing these genes can be used to produce sorghum varieties with high levels of tannins, which are powerful antioxidants thought to protect against cancer.

6. Kernel Genetics Impact Levels of Antioxidants. The effects of plant color, pericarp thickness, pigmented testa, and spreader genes on total phenols and antioxidant activity levels of thirteen sorghum genotypes were evaluated. In vitro antioxidant activity levels were determined using two different assays. Sorghums with dominant B1B2 genes had the highest antioxidant activity, especially varieties with the dominant S gene. This antioxidant activity came mainly from condensed tannins, which have demonstrated higher antioxidant activity in vitro than other phenolic compounds.

Plant color and pericarp thickness also affect antioxidant activity. Sorghums from purple/red plants had higher antioxidant activity than those from tan plants. From the purple/red plant category, sorghum grains with a thick pericarp had higher antioxidant activity than those with a thin pericarp. A strong correlation between total phenols and antioxidant activity was observed (total phenols vs. ABTS, $r = 0.99$; total phenols vs. DPPH, $r = 0.98$). This suggests that total phenols can be used to evaluate sorghums for antioxidant activity efficiently. As a result, these tests can be used to screen germplasm for the presence of antioxidant activity and are simpler to use than other existing antioxidant assays.

7. Sorghum Produces Excellent Food Ingredients. A number of new and different food products (see picture on following page) were generated from sorghum. The tannin and black sorghum brans and whole grains were extruded to produce snack foods that were quite acceptable. A gluten-free bread containing increased levels of dietary fiber, antioxidants and omega 3 fatty acids was made with sorghum flour, bran, inulin, corn and tuber starches. A bread machine mix containing sorghum bran, gluten and flax seed made excellent bread. Sorghum bran added to ground beef patties was an excellent antioxidant equal to or better than synthetic antioxidants. These food products demonstrate that it is possible to add sorghum bran to food products to raise the antioxidant levels or improve product quality, while maintaining high quality and consumer acceptance.

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Different food products made from sorghum flour.

8. Sorghum Compounds May Lead to Decreased Urinary Tract Infections. The structure of sorghum tannins may influence their nutritional benefits. To investigate this, we have developed a method for distinguishing between tannins with a doubly linked (A-type) interflavan bond from those with a single interflavan bond (B-type). Analysis of the spectra of sorghum procyanidins (tannins) indicate that although the main oligomer mass corresponds to procyanidins with all B-type interflavan bonds, there are also procyanidins with 1 and 2 A-type interflavan bonds. These differences are important because proanthocyanidins with A-type interflavan bonds inhibit the adhesion of pathogenic *E. coli* bacteria to cells in the urinary tract and consumption of foods with A-type proanthocyanidins may decrease risk of urinary tract infections. Thus, sorghum lines containing the A-type proanthocyanidins may prove to be a valuable source of nutraceuticals.

Goals for 2006, 2007, and 2008:

Specific tasks for 2006 will be to:

1. Conduct wet milling, dry milling, extrusion and fermentation quality analysis of selected sorghum lines. This will allow us to determine the components responsible for processing quality of sorghum. This in turn will enable us to work with breeders to improve the genetic quality of sorghum and to develop rapid methods for predicting sorghum processing quality.

2. Characterize and catalogue the color compounds, phenolics, and other small molecules in sorghum from weathered and sound grain; evaluate grains for markers of insect and fungal damage and infestation. This will allow us to understand the role of color compounds on grain quality, to identify chemical markers of grain quality, and to develop rapid methods for predicting grain quality.

3. Continue optimization of batter type product formulations for production of wheat-free sorghum based foods. Accomplishing this objective will allow us to produce sorghum based food products with improved quality. Such products will provide celiac patients with high quality cereal food products and provide a new market for sorghum producers.

Specific tasks for 2007 will be to:

1. Complete multi-instrument single kernel characterization system (SKCS) comparisons and calibrations of sorghum hardness values with researchers in Kansas, Nebraska, and Texas. There is no current standard method for measuring grain hardness in grain sorghum.

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The SKCS offers the potential for rapid measurement of grain hardness, but multi-instrument trials are needed to verify the use of the instrument.

2. Determine the effect of environment on protein content and composition of isolated hard and soft endosperm fractions. Kernel hardness is an important quality component. Accomplishing this objective will provide us with a biochemical understanding of how the environment can influence protein synthesis and kernel hardness.

3. Investigate visco-elastic dough formation in artificial sorghum protein-starch dough systems and elucidate changes to sorghum proteins during mixing. These changes will be compared to changes observed in wheat proteins during dough development. Accomplishment of this objective will allow us to understand the reasons why sorghum proteins do not form a dough and to determine the conditions that would be necessary to make sorghum proteins form dough. This is the first step in creating sorghum based food products with quality similar to wheat products.

4. Determine the starch and protein content and composition from diverse sorghum lines and relate the results to ethanol and lactic acid yields. Accomplishment of this objective will enable us to fully understand the factors governing ethanol yields in sorghum. By understanding the components and their interactions, methods for screening and predicting ethanol yield can be found. This in turn will allow us to work with breeders to improve the fermentation performance of U. S. sorghum hybrids.

Specific tasks for 2008 will be to:

1. Evaluate exotic germplasm for desirable processing traits (e.g., ethanol yield). Using exotic germplasm in breeding programs can integrate new sources of variability to improve end-use quality traits. Completion of this objective will enable us to judge the variability in exotic germplasm for improving traits such as fermentation quality in sorghum.

2. Determine the extent of protein-protein interaction and protein-starch interaction in artificial sorghum dough systems. This work will continue to examine the factors necessary to produce a visco-elastic dough from sorghum. Accomplishment of this objective will place us closer to producing sorghum food products with quality close to that of wheat.

3. Develop methods for disruption of sorghum protein bodies in sorghum flour to free proteins for interaction during mixing. In order to make a visco-elastic dough directly from sorghum flour, the protein bodies must first be disrupted. This objective will investigate methods for accomplishing this.

Specific Cooperative Agreements for This Project Included:

a. Department of Biological and Agricultural Engineering, Kansas State University, Manhattan, Kansas

b. Department of Biological Systems Engineering, University of Nebraska, Lincoln, Nebraska

c. Department of Soil and Crop Sciences, Texas A&M University, College Station, Texas

d. Department of Animal Sciences, University of Wisconsin, Madison, Wisconsin

e. Department of Pharmaceutical and Biomedical Sciences, University of Georgia, Athens, Georgia

f. Department of Food Science and Nutrition, Texas A&M University, College Station, Texas

Summary of 2005 Publications/Patents:

1. Razote, E.B., Maghirang, R.G., Seitz, L.M., Jeon, I.J. Characterization of volatile organic compounds on airborne dust in a swine finishing barn. 2004. Transactions of the ASAE. v. 47. p. 1231-1238.

2. Schober, T., Messerschmidt, M., Bean, S., Park, S.H., Arendt, E.K. Gluten-free bread from sorghum: quality differences among hybrids. 2005.Cereal Chemistry. v. 82. p. 394-404.

3. Pedersen J.F., Bean, R.S., Graybosch, R.A., Park, S.H., and Tilley, M. Characterization of waxy grain sorghum lines in relation to granule bound starch synthetase. 2005. Euphytica v. 144. p. 151-156.

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CRIS 5430-44000-018-00D

Enhancement of Hard Winter Wheat Quality and Its Utility
(Hard Winter Wheat Quality Laboratory)

Project Leader: B. Seabourne

Investigators: O. Chung, B. Seabourn, and Vacant

Full-Time Scientist Equivalents (SYs): 3.0

Start Date: 10/01/04

Term Date: 09/30/09

Problem: Wheat is the world's most important crop, in terms of both total acreage planted and human consumption. The wheat marketing system in the U.S. is based primarily on physical rather than intrinsic end-use quality. In order to survive stiff competition in the global wheat market, the U.S. must deliver a high quality product to its customers. This can only be achieved when U.S. wheat growers produce a crop with end-use properties desired by the buyers (domestic and international), and are rewarded for crop quality as well as yield.

Therefore, rapid, objective and accurate predictive methods and technologies must be developed to segregate grain based on quality attributes in order for producers to be rewarded for crop quality. From a breeding perspective, development and release of a single new wheat cultivar into the commercial market requires 13-15 years of research at a cost of approximately $1 M, while the useful lifespan of a new wheat variety is approximately 3-5 years after its release. Without intrinsic quality evaluation, long range wheat breeding programs in the U.S. face the risk of releasing cultivars of unknown quality and with disastrous economic impact. Consequently, breeding wheat for quality is the first step toward keeping U.S. wheat competitive in world markets. Standard methods for evaluating hard winter wheat quality in advanced generations (pre-release) include milling, mixing, and production of baked products such as bread. The use of early generation quality predictive tests (if they existed) could save breeders considerable time and money. In addition, accurate early methods for determining quality would enable breeders to segregate their new lines based on the end-use performance needed for a wide range of specific products. This would help prevent the loss of potential varieties that are ideally suited for noodle or tortilla production.

Wheat bread is a major staple in the world. Millions of loaves of bread per day are produced in automated bakeries in the U.S. The more automated a process becomes, the less opportunity there is for people operating the bakery to make changes that induce undesirable variations in wheat flour properties. Since doughs are made in 2,000 pound batches, if the dough cannot be used due to variations in its properties, such as stickiness or shorter mixing time requirement, the bakery would have to throw out that batch and clean the entire system at a cost of about $10,000. If the problem is not found until the bread comes out of the oven, then the cost rises to $132,000 per batch due to the number of batches that are in the system when the problem is found. These costs include costs associated with utilities, cleanup, and lost product. The mixing of dough, as it is practiced commercially or in the quality control laboratory, has been largely one of visual and tactile observations of the dough mass as it changes in color and texture, consistency, and stickiness, or its response to work input via the mixograph, farinograph, or some other imitative device. Thus, current practices are largely subjective in nature. A more objective method for measuring the rheology of dough systems, preferably one based on physical-chemical aspects of dough component interactions, has long been desired by cereal chemists. Therefore, rapid methods to predict wheat flour quality, without expensive and time-consuming tests such as test baking are urgently needed by the baking industry. Furthermore, rapid prediction methods for breadmaking quality would enhance the U.S. export of hard winter wheat because international buyers of U.S. wheat want to know what quality they are receiving prior to purchase.

The HWWQL provides the critical link in the development of new hard winter wheat varieties in the U.S. However, this has traditionally required the breeder to spend a large amount of time evaluating raw quality data. Therefore, the HWWQL developed a simple, user-friendly relational database system to quickly summarize and interpret end-use quality data. The database offers tremendous flexibility in that it allows the breeder to change the algorithms by which the database evaluates and interprets end-use quality. Due to the multi-faceted nature of the entire wheat industry, a definition of quality will vary markedly. With our database, the breeder can "define" quality according to his/her end-use product or targeted customer preference. Food manufacturers and other customers can also use the information in this database, which is updated on a yearly basis, to determine which varieties possess the quality traits needed to make each of the products that they produce.

This project addresses several problems regarding the enhancement of quality parameters that are keys to ensuring the value of U.S. grain, specifically the program components to "develop rapid, non-destructive quality measurements for grains." These investigations will provide a basis for release of U.S. hard winter wheat cultivars with desirable intrinsic end-use quality, and with shortened cultivar development and release time. Tests and reference methods will be developed to rapidly, objectively, and accurately predict end-use quality and verify the quality content of U.S. hard winter wheat (identity preserved) and products, including traditional bread products, as well as non-traditional products, such as tortillas or Asian noodles. Results from our work will add greater value to U.S. hard winter wheat, and enhance the wheat marketing system with more emphasis on its intrinsic end-use quality rather than physical quality attributes alone. Project outcomes will directly benefit wheat breeders with the selection of good quality hard winter wheat progenies, as well as grain marketing channels that will be able to segregate shipments based on their end-use properties. Ultimately, all sectors of the wheat industry will benefit from this project.

Objectives: Recent changes in the international marketing of wheat require simple, inexpensive, fast and accurate tests to enable buyers to identify wheat samples with specific end-use properties at the first point of sale. The current wheat marketing system is primarily based on physical rather than intrinsic end-use quality.

In order to survive stiff competition in the global wheat market, it is imperative for U.S.

producers to deliver a crop with end-use properties desired by buyers (both domestic and international), as well as for producers to be rewarded for the quality of their crop in addition to yield. Therefore, developing rapid, accurate and objective end-use quality predictors for the breeding community and the grain industry is one of our main objectives.

Quality prediction systems are being developed using near-infrared (NIR) reflectance/transmittance spectral data combined with milling/dough/bread quality data. In addition, in order to expand the usage of hard winter wheat into non-bread products, such as Asian noodles and tortillas, we are developing small-scale testing methods for noodles and tortillas to evaluate early generation breeding lines with the ultimate goal of predicting non-bread product quality.

Results and Impact:

1. Mystery of Frozen Dough Functionality Solved. The use of frozen dough has become an increasingly popular alternative to conventional dough processing in the commercial bakery in the last decade. It provides the benefit of producing a fresh baked product while saving on equipment and labor costs. However, frozen dough produces a poorer quality product than fresh dough, including longer proof times, smaller loaf, poorer texture, and variable end-use performance. We hypothesized that the change in gluten structure in frozen dough could be one of the reasons that frozen dough has a poorer end-use performance than fresh dough. Hard Red Winter (HRW) wheat flours of varying protein content and mixograph mixing time were mixed to optimum using a mixograph then frozen for 24 hours, 1 week, and 2 weeks, respectively. After thawing, the dough samples were scanned using mid-IR spectroscopy. Spectral analysis of all the samples showed that the most significant change occurred within the three-dimensional structure of the proteins. The greatest change occurred within the first 24 hr of storage. Changes in the 3D-structure of the gluten after freezing and thawing cycles were opposite from the changes in 3D-structure typically observed during the dough-mixing and development process. Structural characteristics of gluten proteins in frozen and thawed dough were similar to those of under-mixed or undeveloped dough, which might be one of the reasons why frozen dough typically has inferior end-use performance to fresh mixed dough.

2. NIR Calibrations for Wheat Quality Traits Improved. Calibrations for Asian noodle color prediction were revised to include the latest crop year data from the HWWQL. The results of this work yielded calibrations with r^2 values of up to 0.84 for noodle color prediction at 24 hr. It is expected that these calibrations will continue to improve with the continued accumulation of sample data since we only have a few crop years of data for this new test within the HWWQL.

We also continued development of NIR calibrations for flour ash, which has been difficult to accomplish due to the narrow range of ash values, for the advanced experimental lines typically seen in the HWWQL. This work yielded calibrations with r^2 values of 0.81. Continued work with these equations will involve incorporating data from various millstreams to add more variation and range to the calibration set.

3. Hard Winter Wheat Quality Laboratory (HWWQL) Generates New Web Page to Provide Information to Breeders, Producers, and Other Industry Customers.

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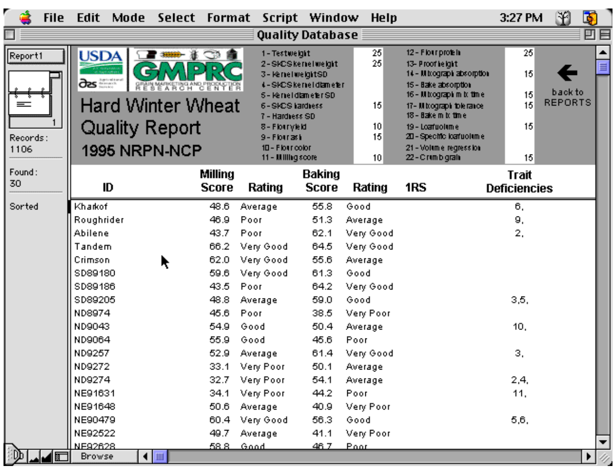
A webpage for the HWWQL was developed so that breeders and other industry customers could easily access both past and present regional performance nursery data via the internet. Interested parties can immediately obtain HWWQL data from crop years as far back as 1972. The webpage also allows for the HWWQL to more rapidly respond to customer needs, concerns, and requests for quality analysis, through various user-friendly forms, which are immediately forwarded to the HWWQL director. In addition to nursery data, the webpage describes in detail the analytical methods and techniques used by the HWWQL to evaluate wheat and flour quality. Thus, the webpage provides a closer relationship between HWWQL personnel and our customers. The webpage can be found at http://www.ars.usda.gov/main/HWWQL/HWWQLHome.htm.



Example of HWWQL Quality Report.

We have developed a simple, user friendly relational database system (currently distributed on CD free of charge) that summarizes and interprets end use quality data. This database allows breeders to more rapidly and accurately assess the quality potential of experimental breeding lines, and ultimately facilitates the increased utilization of U.S. wheat flour for new and unique commercial products. The immediate and direct impact on the wheat industry has been to facilitate the removal of undesirable lines from early generation tests more rapidly, thereby decreasing the time and expense of development for new varieties.

4. NIR Becoming a More Useful Tool for Timely Prediction of Hard Winter Wheat Flour Quality and Analysis of the Impact of Chemical Oxidizing/Reducing Agents. Each year, the prediction equations developed using NIR technology are being fine tuned utilizing new crop data. Current prediction equations allow the HWWQL to simultaneously screen flour samples in less that 30 sec. for protein content, moisture content, ash content, flour color, mixograph water absorption, bake water absorption, and pup loaf volume of bread using 100-g flour. This technology has displaced more traditional and time-consuming methods of analysis used by the HWWQL, and thus provides a more rapid and cost-effective means of providing quality data to our customers with little or no loss in accuracy or precision.

In one specific project, NIR spectroscopy was used in the analysis of a flour water dough system as the dough was mixed with a computerized mixograph. Real time NIR spectral data were collected on dough made with hard winter wheat flours obtained from federal regional performance nurseries. Significant changes in the protein region of the near infrared occurred after the dough had been chemically modified with oxidizing and reducing agents.

Further study revealed mid-IR bands associated with changes in the three-dimensional structure of dough proteins. These bands were identified and found to be highly correlated with the mixogram curves. Results showed that it is possible, using

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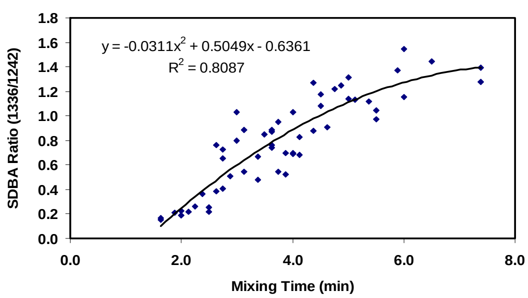
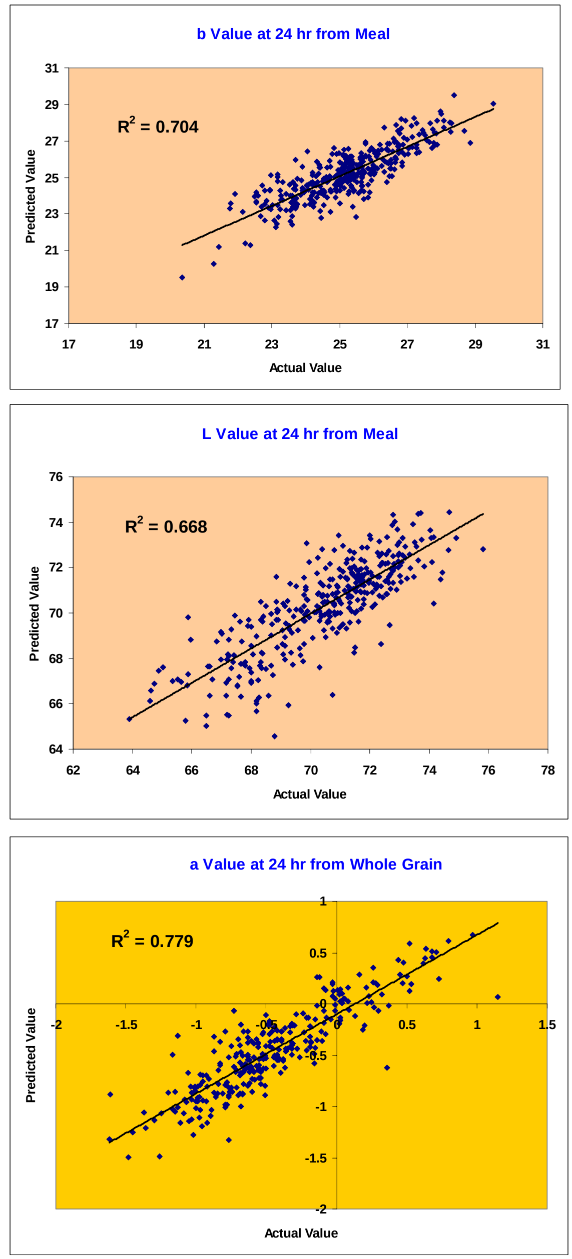
infrared spectroscopy, to accurately and objectively monitor the rheology of dough systems based on changes in the protein structure of the system, and without the need for subjective tests such as the mixograph, farinograph, etc., which simply measure the physical response of the dough to work input. Additional studies showed a high correlation of the three-dimensional structure of the dough system from as early as one minute of mixing to the optimum mixing time (see graph below).



Plot of 3d-structural ratios versus mixing time.

5. Prediction of Asian Alkaline Noodle Color and Polyphenol Oxidase Activity Using NIR Spectroscopy of Whole Wheat, Meal, and Flour. Noodle color is an important quality trait to wheat breeders as well as consumers. This study investigated the potential of NIR spectroscopy to predict noodle color and polyphenol oxidase (PPO) content directly from whole grain, meal, and flour. A total of 585 hard winter wheat samples (375 for calibration and 210 for validation) harvested in 2002 and 2003 were used. Calibration models were developed for predicting noodle color (L*, a*, and b* at 0 and 24 hr) and PPO content from grain, meal, and flour. Calibration model R-square values for PPO content were generally lower than those for noodle color. For noodle color, the highest R-square value was for L* at 24 hr from flour (0.84 and 0.68 for calibration and



NIR predictions plotted versus actual values for L, a, and b.

validation, respectively), with an RPD of 2.46. Other calibration models for noodle color at 0 and 24 hr from whole grain and meal also showed very comparable R-square values with an even higher RPD. The highest R-square values for a* and b* at 24 hr were 0.82 and 0.84 for calibration, and 0.78 and 0.70 for validation with RPD values of 3.23 and 2.98, respectively. The data suggest that there is a good potential for predicting noodle color using NIR spectra from such basic materials as grain, meal, and flour.

6. Prediction Models Developed for Cooked Noodle Texture. Due to increasing uses of hard winter wheat (HWW) in other than bread products, the Hard Winter Wheat Quality Laboratory included Asian alkaline noodle-making in the quality evaluation of the breeding program. Since the textural measurement of cooked noodle quality is too labor-intensive for thousands of breeding lines, we investigated relationships of texture profile analysis (TPA) values of cooked alkaline noodles of 34 HWW with quick tests generally used for bread quality estimation, i.e., SRC, SDS-sedimentation, computerized mixograph, and protein content.

We found many significant correlations among TPA values of cooked noodles including hardness, resilience, adhesiveness, and cohesiveness and quality traits. The prediction model, however, was developed using only protein content and computerized mixograph data, resulting in R-square values of 0.67, 0.54, and 0.71 for cooked noodle hardness, resilience, and cohesiveness. The addition of SRC, SDS-sedimentation, and/or IPP data, the R-square of prediction models were improved only marginally, indicating the potential that most routinely analyzed data, protein content and computerized mixograph data, especially time-x values, could be used for predicting cooked noodle textures for the HWW breeding program.

7. Adaptation of Solvent Retention Capacity (SRC) Test to Evaluate Hard Winter Wheat Quality. We investigated the suitability of SRC in assessing HWW product quality. We measured the SRC values of 116 HWW samples with 5% lactic acid, 50% sucrose, 5% sodium carbonate and water. We found that 5% lactic acid SRC showed the highest correlation with loaf volume (r = 0.83, P<0.0001) of all SRC tests. A prediction model for loaf volume was developed using the data from SKCS, NIR, and flour protein and ash (R-square = 0.609, RMSE = 75.6), and this model was improved with inclusion of 5% lactic acid SRC values (R-square = 0.778, RMSE = 57.2).

Goals for 2006, 2007, and 2008:

Specific tasks in 2006 will be to:

1. Continue to add graphic images of the mixograph curve for each wheat line in the HWWQL database for the next release of the database, as well as an interface for user-selected statistical analyses; a new, online real-time version of the database will be launched for even easier access to the HWWQL data via the worldwide web.

2. Study both genetic and environmental effects on end-use quality and biochemical components (composition) with breeder's samples grown at various locations.

3. Continue with the instrumental analyses of the interaction of the various chemical components in flour during dough formation.

4. Investigate the breadmaking quality relationships between various methods (pound loaf, pup loaf, and micro-loaves using 35-g, 10-g, and 2-g flour) to obtain the conversion factors for loaf volume.

5. Continue to develop an understanding of the changes that occur in proteins, starches, and lipids during dough formation.

6. Use FTIR to measure the changes in the secondary structure of the gluten matrix in dough during mixing and factors that determine optimum dough development.

7. Incorporate fundamental wavelengths responsible for end-use performance into existing NIR instrumentation for use in the commercial industry.

8. Fine tune prediction models of wheat quality factors using several cereal testing instruments linked to the biochemical data from the MU's sister CRIS.

9. Test NIR prediction calibration for these color constituents or PPO for accuracy and stability in the HWWQL as part of our routine quality analysis.

10. Continue the development of simple and inexpensive analytical techniques to measure components that relate to wheat end-use quality, including color, polyphenol oxidase (PPO), or nutritional factors in wheat.

11. Continue the development of simple and inexpensive analytical techniques to measure components that relate to quality factors in wheat for non-bread products including noodles and tortillas.

12. Continue the development of simple and inexpensive analytical techniques to measure components that relate to quality factors in wheat, including non-bread products, noodles and tortillas.

Specific tasks in 2007 will be to:

1. Continue to improve/develop the small-scale procedures of various wheat products, including bread, noodles, tortillas, etc. The quality data will be added to the development of quality-prediction models.

2. Finalize the quality prediction system for wheat breeding lines.

3. Study both genetic and environmental effects on protein and lipid contents and composition with breeders samples grown at various locations.

4. Use FTIR and Raman analyses to evaluate the influence of specific added dough ingredients such as sugar, salt, oxidizing/reducing agents, and shortening on the behavior of dough protein secondary structure during mixing and its relationship to end-use performance.

5. Use FTIR and Raman analyses to evaluate the influence of specific bonds such as disulfide or dityrosine bonds within individual protein molecules and between proteins or other chemical constituents on end-use performance.

6. Develop a rapid (1-2 min) spectroscopic test to estimate optimum mixograph mix time for quality evaluation purposes in wheat breeding programs.

7. Continue to improve/develop the small-scale procedures of various wheat products, including bread, noodles, tortillas, etc.

8. Begin screening breeder samples for PPO, noodle color, and noodle-making quality to test calibration accuracy as well as assist breeders in identifying breeding lines with undesirable quality traits.

9. Continue to improve/develop the small-scale procedures of various wheat products, including bread, noodles, tortillas, etc. The quality data will be added to the development of quality-prediction models.

10. Continue efforts to improve/develop the small-scale procedures of various wheat products, including bread.

11. Establish texture analyzing processes for raw and cooked noodles.

12. Begin to develop small scale rheological methods and analyze the molecular size distribution of tortilla dough proteins to predict end-use properties of tortillas.

Specific tasks in 2008 will be to:

1. Continue to improve or develop simple and inexpensive analytical techniques to measure components that relate to variety or nutritional factors in wheat. An NIR prediction calibration for the color constituents, certain nutrients or enzymes such as PPO will be tested for accuracy and stability in the HWWQL as part of our routine quality analysis.

2. Investigate the effect of variation in kernel hardness and weight in a wheat sample on milling and baking properties and continue to study the relationships between wheat physical characteristics and end-use properties, which may be used to segregate wheat based on quality.

3. Continue to fine-tune the prediction systems of wheat quality to be useful in marketing channels.

4. Use FTIR and Raman analyses to evaluate the influence of various mixers (type of work input) and mixing speed (rate of work input) on the behavior of dough protein secondary structure during mixing and its relationship to end-use performance.

5. Study protein-starch, protein-lipid, and starch-lipid interactions in a model system during mixing, fermentation, and baking stages; and determine the influence of various standard ingredients on dough rheology by FTIR.

6. Continue to improve or develop simple and inexpensive analytical techniques to measure components that relate to variety or nutritional factors in wheat. An NIR prediction calibration for the color constituents, certain nutrients or enzymes such as PPO will be validated for accuracy and stability in the HWWQL as part of our routine quality analysis.

7. Continue to fine-tune the prediction systems of wheat quality to be useful in marketing channels.

8. Screen breeder samples for PPO, noodle color, and eating quality, based on a texture analysis of raw and cooked noodles.

9. Continue to improve or develop simple and inexpensive analytical techniques to measure components that relate to variety or nutritional factors in wheats. An NIR prediction calibration for the color constituents, certain nutrients or enzymes such as PPO, will be tested for accuracy and stability in the HWWQL as part of our routine quality analysis.

10. Fine-tune the prediction systems of wheat quality to be useful at the marketing channel. We plan to finalize the quality-prediction system for wheat breeding lines.

11. Continue to improve or develop simple and inexpensive analytical techniques to measure components that relate to variety or nutritional factors in wheat. An NIR prediction calibration for the color constituents, certain nutrients or enzymes such as PPO, will be tested for accuracy and stability in the

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HWWQL as part of our routine quality analysis.

12. Continue to fine-tune the prediction systems of wheat quality to be useful in marketing channels.

13. Continue to provide early generation information to breeders that predict the tortilla making properties of wheat.

Specific Cooperative Agreements for This Project Included:

a. Department of Grain Science and Industry, Kansas State University, Manhattan, Kansas

Summary of 2005 Publications/Patents:

1. Hubbard, J.D., Downing, J.D., Ram, M.S., Chung, O.K. Lipid extraction from wheat flour using supercritical fluid extraction. 2004. Cereal Chemistry. v. 81. p. 693-698.

For More Information on This Project Contact:

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PLANT SCIENCE AND ENTOMOLOGY RESEARCH UNIT

The mission of the Plant Science and Entomology Research Unit is to support the U.S. wheat industry by developing and providing genetic solutions to economically important biotic and abiotic stress problems in hard winter wheat. We will focus on resistance or tolerance to several recalcitrant or emerging problems that impact grain production and/or quality. In addition, the Unit hosts a Cereal Crop Genotyping Laboratory that will provide marker-assisted selection research and services to public and private wheat breeders. The specific research project for this Unit is:

CRIS - 5430-21000-005-00D	Genetic Enhancement for Resistance to Biotic and Abiotic Stresses in Hard Winter Wheat

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CRIS 5430-21000-005-00D

Genetic Enhancement for Resistance to Biotic and Abiotic Stresses in Hard Winter Wheat

Project Leader: R. Bowden

Investigators: R. Bowden, J. Fellers, M. Chen, G. Bai, Z. Ristic, and vacant Research Geneticist position

Full-Time Scientist Equivalents (SYs): 6.0

Start Date: 07/19/03

Term Date: 07/18/08

Problem: In the USA, winter wheat (both hard and soft types) is planted on approximately 35 million acres annually and the farm gate value is approximately 4 billion dollars. In the central and southern Great Plains region, winter wheat is the most important crop and many rural communities are highly dependent upon it. Approximately 50% of the wheat produced in this region is shipped internationally and supports a large wheat export industry. In addition to its value as a grain crop, wheat is also used as an important cool season pasture crop for the livestock industry.

Yields of wheat in the central and southern Great Plains are typically less than half of those achieved in more favorable environments, such as the Pacific Northwest. The difference between actual and attainable yields is due to multiple biotic (diseases and insects) and abiotic (heat and drought) stress factors. In addition to yield losses, these stresses also cause losses in grain quality. Host plant resistance or tolerance to these biotic and abiotic stresses is the most economical and environmentally sound method of stabilizing and increasing wheat yields and protecting grain quality in this challenging environment.

Objectives: The goals of this project are to: a) Identify new sources of resistance or tolerance and move the genes responsible into adapted hard winter wheat germplasm; b) Develop new molecular markers (small unique pieces of DNA that are associated with traits of interest) and methods for marker-assisted selection for these traits; c) Develop basic information about host plant resistance and parasite virulence that will lead to improved strategies for selection and utilization of genetic resources; and d) Provide adapted wheat germplasms containing resistance genes and molecular markers, genotyping data, and improved selection methods and strategies to public and private wheat breeders for use in producing new varieties with multiple resistances or tolerances to biotic and abiotic stresses.

Results and Impact:

1. New Genes Found for Resistance to Fusarium Head Blight of Wheat. A specific chromosome region that harbors the genes controlling a specific plant trait is called a quantitative trait locus (QTL). In 2005, we identified several new QTLs for Fusarium head blight (FHB) resistance from a Korean wheat cultivar, Chokwang, by using the QTL mapping technique. Several hundred molecular markers were screened in a wheat population of recombinant inbred lines derived from the cross between resistant variety (Chokwang) and susceptible variety (Clark) parents. One new QTL was identified on the long arm of chromosome 5D. Another new QTL mapped on the long arm of chromosome 4B. A third QTL on chromosome 3BS with minor effect on FHB resistance was also detected in this population. These results suggested that Chokwang contains new genes for FHB resistance that are different from those in the well-studied resistance source, Sumai#3. Combining resistance genes from these two sources may enhance FHB resistance in wheat cultivars

2. Five Wheat Germplasm Lines Released with Resistance to Diseases. Five wheat germplasm lines were jointly developed with Kansas State University and were deposited in the Wheat Genetics Resource Center at Kansas State University. Traits of these lines included resistance to leaf rust, Fusarium head blight, powdery mildew, and a unique high molecular weight glutenin. These germplasm lines will be used by wheat breeders to develop improved wheat cultivars for the future. Small quantities of seed are available on request.

3. Hessian Fly Resistance Gene Clusters Located in Wheat. The chromosomal locations were determined for two clusters of Hessian fly resistance genes, the H9 and H13 gene clusters. The significance of this work is that we now have a set of tightly linked markers for each of the two clusters that can be used for marker-assisted selection for breeders.

This is particularly important because the two clusters were incorrectly assigned to wrong chromosomal locations in previous literature. The H9 gene cluster was incorrectly assigned to the short arm of chromosome 5A while the H13 cluster was wrongly assigned to the long arm of chromosome 6D. Our research revealed that the H9 cluster is located on the short arm of chromosome 1A while the H13 cluster is located on the short arm of chromosome 6D. The H9 gene cluster consists of at least 11 Hessian fly resistance genes (H3, H5, H6, H12, H14, H15, H16, H17, H19, H28, and H29). The H13 cluster contains 3 Hessian fly resistance genes (H13, H23, and an unnamed gene), one wheat curl mite resistance gene (Cmc4), and a defense response gene (Ppo).

Therefore, this research provided markers for a range of Hessian fly resistance genes for marker assisted selection, which will accelerate breeding for Hessian fly resistance and provide a way for multiple genes carrying this trait to be incorporated into new cultivars. In addition, our results provide a foundation for eventual cloning of these resistance genes in the future. Cloning of the resistance genes could result in transgenic wheat lines with improved Hessian fly resistance.

4. Hessian Fly Guts May Provide Clues to Parasitism of Wheat. Salivary glands and the gut of an insect are two tissues that are critical in understanding the interaction between host plants and insects. Previously, we systematically analyzed the genes expressed in Hessian fly salivary glands. In the past year, we analyzed the genes expressed in Hessian fly gut tissues following a similar approach. Through this analysis, we discovered major digestive enzymes, detoxification enzymes, and defensive proteins in the Hessian fly gut. This study provided a foundation for understanding of digestive physiology of the insect and for the understanding of the interaction between wheat and the Hessian fly. A better understanding of the digestive physiology of the Hessian fly may eventually lead to the development of plants with defensive proteins such as protease inhibitors which inhibit feeding and digestion by Hessian fly larvae.

5. Chloroplast Protein Provides Heat Tolerance in Maize. Previous studies have suggested that the gene that codes for chloroplast protein synthesis elongation factor, EF-Tu, may be of importance to heat tolerance. Using maize as a model system, a new study revealed a strong positive correlation between the expression of EF-Tu and plant heat tolerance. In addition, the results of this study also revealed that the regulation of the expression of EF-Tu may be different in heat tolerant and heat sensitive plants. This study strongly supports the hypothesis that EF-Tu plays an important role in plant heat tolerance. A new study was recently initiated to investigate the potential role of chloroplast EF-Tu in heat tolerance in wheat.

6. Wheat Rust Fungus Arsenal Probed. Avirulence genes (genes that trigger resistance reactions in the plant) are important determinants of resistance or susceptibility of wheat to rust diseases. We recently developed a new method to tag and clone genes of interest in the wheat leaf rust fungus (*Puccinia triticina*). This method may accelerate discovery and cloning of avirulence genes, which are crucial to triggering the susceptibility or resistance of the plant. Greater understanding of avirulence genes may help in designing more durable resistance to the rusts.

7. Fusarium Head Blight Fungus Genetic Map Aligned with Sequence. We aligned the genetic map of *Gibberella zeae* with the first assembly of the genomic sequence of strain PH-1 (lineage 7) that was released by The Broad Institute (Cambridge, MA). The alignments grouped the linkage groups and supercontigs into four sets, confirming that there are four chromosomes in this fungus. Approximately 99% of the sequence was anchored to the genetic map, indicating the high quality of the sequence assembly and the relative completeness and validity of the genetic map. This resource will be useful in studying the genes controlling the ability of this important plant disease to establish itself in a wheat plant. This work is in collaboration with scientists at Kansas State University.

8. Aluminum Tolerance May Be a Complicated Genetic Complex. Aluminum (Al) toxicity in acidic soils is a major constraint on wheat production in the southern Great Plains. Aluminum tolerant cultivars are known, but the mechanism of tolerance is not well characterized. In this study collaborative with Oklahoma State University, a major quantitative trait locus (QTL) for Al tolerance was located on the long arm of chromosome 4D of the wheat cultivar Atlas 66. Several markers closely linked to the QTL were identified and could be useful as molecular markers for selection of Al tolerant wheat cultivars in breeding programs.

In another study, a pair of wheat lines differing in Al tolerance was developed by transferring an Al tolerance gene from Atlas 66 (tolerant) to Century (susceptible). Gene expression analysis of the roots that were under Al stress identified several differentially expressed genes with putative functions in signal transduction, oxidative stress alleviation, membrane structure, transport, etc. Therefore, tolerance to Al toxicity in wheat may involve a complicated network of stress-related and metabolic pathways.

9. Mapping of Resistance Genes for Septoria Leaf Blotch and Soilborne Mosaic Virus. Molecular markers can help identify resistant wheat lines without expensive, slow, or inaccurate conventional field screening.

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Seventy-eight lines from a recombinant inbred WGRC40/Wichita population segregating for *Septoria triticii* blotch (STB) and wheat soilborne mosaic virus (WSBMV) resistance were phenotyped for both traits. The segregation ratios from these screenings fit the expected one dominant gene segregation ratio for STB and WSBMV. Using molecular markers, one STB resistance gene appeared to be located on chromosome 7DS. There are two previously reported STB resistance genes (STB4 and STB5) on chromosome 7D. Genetic crosses will be performed this fall to determine if the gene in WGRC40 is a new gene or is one of the two previously reported genes.

Effect of slow rusting resistance gene Lr46 (top) vs. susceptible (bottom) on wheat leaf rust.

10. Location of Durable Leaf Rust Resistance Gene Refined. The gene *Lr46* has provided durable, slow rusting resistance to wheat leaf rust and stripe rust in many regions of the world. Unfortunately, field screening for this type of partial resistance is difficult and molecular markers would be useful. In collaboration with researchers at CIMMYT and Kansas State University, we found markers linked to this gene on a small segment of chromosome 1BL. Molecular markers were developed that are 2 centiMorgans proximal and 0.3 centiMorgans distal to *Lr46*. These tightly linked markers will be very useful for marker-assisted selection and cloning of this durable gene.

11. Breeding for Resistance to Karnal Bunt. Our Unit collaborates with researchers at Oklahoma State University, Texas A&M University, Kansas State University, CIMMYT in Mexico, and Punjab Agricultural University in India to screen wheat lines for resistance to Karnal bunt. Sixty-three advanced lines were evaluated in the third Winter Wheat Karnal Bunt Screening Nursery. Several experimental lines appeared promising. The most interesting line was the Texas breeding line TX01M5009, which appeared to be resistant to KB in numerous replications. The source of the resistance in this line is unknown. Although TX01M5009 has high yield and excellent foliar disease resistance, it has relatively poor bread making quality. This line may be proposed for cooperative release as a germplasm line for resistance to KB in a hard red winter wheat background.

Crosses have been made to several other sources of resistance from India and CIMMYT. Advanced lines from these crosses will need to be tested in future screening nurseries.

Goals for 2006, 2007, and 2008:

Specific tasks in 2006 will be to:

1. Evaluate BC-1 or BC-2-derived breeding lines with major gene resistance to leaf rust in the field and greenhouse. Make selections for germplasm development.

2. Evaluate BC-1 or BC-2-derived breeding populations with minor gene adult plant resistance to rust in the field and greenhouse. Make selections for germplasm development.

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3. Identify linked SSR markers in three mapping populations for resistance to rust and enrich region with additional markers. Markers for slow rusting would be particularly useful.

4. Assay for Avr gene function of rescued genes from *P. triticina*.

5. Evaluate breeding lines with resistance to Hessian fly in the greenhouse. Isolate homozygous lines.

6. Identify linked SSR markers for two mapping populations for novel Hessian fly resistance genes and enrich region with additional markers.

7. Analyze expression of secreted proteins from Hessian fly salivary glands. Submit manuscript.

8. Screen wheat breeding lines from cooperating breeding programs for resistance to Hessian fly.

9. Prepare sets of homozygous breeding lines for testing KB reaction in Mexico and India.

10. Begin phenotyping doubled haploid mapping population for validation of resistance QTLs for Karnal bunt.

11. Perform AFLP analysis on populations of *Tilletia indica*.

12. Screen wheat breeding lines from cooperating breeding programs for resistance to Karnal bunt.

13. Submit manuscripts on QTL analysis of two mapping populations for resistance to Fusarium head blight.

14. Continue experiments to test aggressiveness of 9 lineages of *Fusarium graminearum* on diverse resistant cultivars.

15. Phenotype three mapping populations for heat tolerance genes.

16. Screen wheat breeding lines from cooperating breeding programs for selected molecular markers. The Cereal Genotyping Laboratory will increase the rate of breeding progress on important traits of interest.

17. Characterize wheat lines from two regional nurseries for at least 15 markers. Bench marking of germplasm in regional nurseries will document breeding progress and help to identify useful parents for crossing.

18. Continue genotyping core set of hard winter wheat breeding parents and constructing marker database.

19. Continue integrated collaborative marker-assisted breeding project with regional breeding programs.

20. Phenotype and genotype the mapping population segregating for Rht8 gene.

21. Further analysis of long coleoptile mapping data and submit a manuscript.

22. Genotype and phenotype two mapping populations for pre-harvest sprouting tolerance.
23. Advance new mapping populations for resistance to Fusarium head blight.

Specific tasks in 2007 will be to:

1. Inheritance studies on major gene resistance to leaf rust. Continue evaluations in the field and greenhouse.

2. Continue to evaluate breeding populations with minor gene adult plant resistance to rust in the field and greenhouse.

3. Confirmation of markers for resistance to rust.

4. Submit manuscript on Avr gene from *Puccinia triticina*. Knowledge of Avr genes will help design strategies for durable resistance in the future.

5. Evaluate breeding lines with resistance to Hessian fly in the greenhouse. Determine inheritance of resistance.

6. Confirm marker effects for Hessian fly resistance genes.

7. Mutation analysis of secreted proteins from Hessian fly salivary glands. Submit manuscript. Secreted proteins are most likely determinative of resistance and susceptibility to Hessian fly. Understanding these effectors will help in design of durable resistance.

8. Screen wheat breeding lines from cooperating breeding programs for resistance to Hessian fly.

9. Evaluate breeding lines for testing KB reaction in Kansas, Mexico and India. Select resistant adapted lines.

10. Submit manuscript on markers for Karnal bunt. Marker-assisted selection for Karnal bunt would be potentially cheaper and more reliable than field screening.

11. Analyze AFLP data on populations of *Tilletia indica*. Submit manuscript. Understanding the population structure of *T. indica* may help in gene deployment strategies.

12. Screen wheat breeding lines from cooperating breeding programs for resistance to Karnal bunt.

13. Advance new mapping populations for resistance to Fusarium head blight and phenotype the populations.

14. Submit manuscript on aggressiveness of 9 lineages of *Fusarium graminearum* on diverse resistant cultivars. This information may be useful in pest risk assessment and breeding strategies.

15. Genotyping and QTL analysis of three mapping populations for heat tolerance genes.

16. Screen wheat breeding lines from cooperating breeding programs for selected molecular markers.

17. Characterize wheat lines from two regional nurseries with markers for at least 15 traits.

18. Continue integrated collaborative marker-assisted breeding project with regional breeding programs.

19. Analyze Rht8 gene mapping data and submit manuscript.

20. QTL analysis of two populations for pre-harvest sprouting tolerance.

Specific tasks in 2008 will be to:

1. Release two or more germplasms with major gene resistance to leaf rust. These will be used by wheat breeders to increase resistance to leaf rusts. Major gene resistance may be most useful for controlling fall epidemics of leaf rust in the southern Plains.

2. Release two or more germplasms with minor gene adult plant resistance to rust. These will be used by wheat breeders to increase resistance to leaf rusts. Minor gene resistance may be more durable than major gene resistance.

3. Submit manuscripts on markers for resistance to rust.

4. Release one or more germplasms with resistance to Hessian fly.

5. Submit manuscript on markers for Hessian fly resistance genes.

6. Western blots of secreted proteins in cells from Hessian fly. Submit manuscript.

7. Screen wheat breeding lines from cooperating breeding programs for resistance to Hessian fly.

8. Release two or more germplasms with resistance to Karnal bunt.

9. Screen wheat breeding lines from cooperating breeding programs for resistance to Karnal bunt.

10. QTL analysis on the new mapping populations for resistance to Fusarium head blight.

11. Release markers for heat tolerance genes. Submit manuscript.

12. Screen wheat breeding lines from cooperating breeding programs for selected molecular markers.

13. Characterize wheat lines from two regional nurseries with markers for at least 15 markers.

14. Complete integrated collaborative marker-assisted breeding project with regional breeding programs. Release germplasm and/or cultivars.

15. Submit manuscripts on pre-harvest sprouting tolerance mapping.

Specific Cooperative Agreements for This Project Included:

a. The Department of Entomology, Kansas State University, Manhattan, Kansas

b. The Department of Plant Pathology, Kansas State University, Manhattan, Kansas

c. The Department of Agronomy, Kansas State University, Manhattan, Kansas

d. The Department of Grain Science and Industry, Kansas State University, Manhattan, Kansas

e. The Department of Biology, Kansas State University, Manhattan, Kansas

f. Agricultural Experiment Station, Texas A&M University, College Station, Texas

g. The Department of Soil and Crop Sciences, Texas A&M University, College Station, Texas

h. The Department of Plant & Soil Sciences, Oklahoma State University, Stillwater, Oklahoma

i. International Center for Maize and Wheat Improvement, Mexico D.F., Mexico

Summary of 2005 Publications/Patents:

1. Brown Guedira, G.L., Hatchett, J.H., Chen, M., Liu, X., Fritz, A.K., Owuoche, J.O., Gill,

B.S., Sears, R.G., Cox, T.S. Registration of ks99wgrc42 hessian fly resistant hard red winter wheat germplasm. 2005. Crop Science. v. 45. p. 805-805.

2. Chen, J., Tauer, C.G., Bai, G., Huang, Y., Payton, M.E., Holley, A.G. Bidirectional introgression between pinus taeda and pinus echinata: evidence from morphological and molecular data. 2004. Canadian Journal of Forest Research. v. 34. p. 2508-2516.

3. Jiang, W., Garrett, K.A., Peterson, D.E., Harvey, T.L., Bowden, R.L., Fang, L. The window of risk for emigration of wheat streak mosaic virus varies with host eradication method. 2005. Plant Disease. v. 89. p. 853-858.

4. Kim, Y., Brown Guedira, G.L., Cox, T.S., Bockus, W.W. Inheritance of resistance to *Stagonospora nodorum* leaf blotch in Kansas winter wheat cultivars. 2004. Plant Disease. v. 88. p. 530-536.

5. Liu, X., Gill, B., Chen, M. Hessian fly resistance gene h13 mapped to a distal cluster of r genes in chromosome 6ds of wheat. 2005. Journal of Theoretical and Applied Genetics. v. 111. p. 243-249.

6. Liu, X.M., Reese, J.C., Wilde, G.E., Fritz, A.K., Gill, B.S., Chen, M. Hessian fly-resistance genes h9, h10, and h11 are mapped to the distal region of wheat chromosome 1as. 2005. Journal of Theoretical and Applied Genetics. v. 10. p. 1473-1480.

7. Rosenberg, M.S., Garrett, K.A., Su, Z., Bowden, R.L. Meta-analysis in plant pathology: synthesizing research results. 2004. Phytopathology. v. 94. p. 1013-1017.

8. Rush, C.M., Stein, J.M., Bowden, R.L., Riemenschneider, R., Boratynski, T., Royer, M.H. Status of karnal bunt of wheat in the United States 1996-2004. 2005. Plant Disease. v. 89. p. 212-223.

9. Singh, S., Franks, C.D., Huang, L., Brown Guedira, G.L., Marshall, D.S., Gill, B.S. Lr41, lr39, and a leaf rust resistance gene from *Aegilops cylindrica* may be allelic and are located on wheat chromosome 2ds. 2004. Journal of Theoretical and Applied Genetics. v. 108. p. 586-591.

10. Wu, Y.Q., Taliaferro, C.M., Bai, G., Anderson, M.P. Aflp analysis of genetic variation in cydodon dactylon (l) pers. var. dactylon. 2004. Genome. v. 47. p. 689-696.

11. Wu, Y.Q., Taliaferro, C.M., Bai, G., Anderson, M.P. Genetic diversity of *Cynodon transvaalensis* burtt-davy and its relatedness to hexaploid *C. dactylon* (l.) pers. as indicated by aflp markers. 2005. Crop Science. v. 45. p. 848-853.

12. Xiao, K., Bai, G., Carver, B. Nylon filter arrays reveal differential expression of ests in wheat roots under aluminum stress. Omics - A 2005. Journal of Integrative Biology. v. 47. p. 839-848.

13. Xu, X., Bai, G., Carver, B., Shaner, G.E., Hunger, R.M. Mapping of qtl prolonging latent period of *Puccinia triticina* infection in wheat. 2005. Theoretical and Applied Genetics. v. 110. p. 244-251.

14. Xu, X., Bai, G., Carver, B.F., Shaner, G.E., Hunger, R.M. Molecular characterization of slow leaf rusting resistance in wheat. 2005. Crop Science. v. 45. p. 758-765.

15. Zhang, X., Zhou, M., Ren, L., Bai, G., Ma, H., Scholten, O.E., Guo, P., Lu, W. Molecular characterization of fusarium head

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blight resistance from wheat variety Wangshubai. 2004. Euphytica. v. 39. p. 59-64.

16. Zhou, W., Kolb, F., Yu, J., Bai, G., Boze, L., Domier, L.L. Molecular characterization of fusarium head blight resistance in Wangshuibai with SSR and AFLP markers. 2004. Genome. v. 47. p. 1137-1143.

17. Zhu, Y., Liu, X., Maddur, A., Oppert, B.S., Chen, M. Cloning and characterization of chymotrypsin- and trypsin-like cDNAs from the gut of the Hessian fly (*Mayetiola destructor* (say)). 2005. Insect Biochemistry and Molecular Biology v. 35. p. 23-32.

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WIND EROSION RESEARCH UNIT

The mission of the Wind Erosion Research Unit is to increase understanding of wind erosion processes; develop reliable predictive tools; develop control practices; and disseminate information and technology for sustaining agriculture, protecting the environment, and conserving natural resources.

Highlighted Activities for 2005.

1. WERU Scientists Interviewed for Public Television. On January 27, Les Kinderknecht, senior producer Smoky Hills Public Television, with Mike Grundy, cameraman, interviewed John Tatarko and Ed Skidmore, WERU Soil Scientists, about various aspects of the "Dust Bowl" and the role of wind erosion research in lessening the likelihood of a reoccurrence. These interviews along with several of people who experienced the "Dust Bowl" were used in Smoky Hills Public Television production of Stories from the Dust Bowl. Smoky Hills also used many pictures from WERU's multimedia archive. Public viewing started on March 13, 2005.

2. Boy Scouts Tour the USDA-ARS Wind Erosion Research Facility. On February 21, John Tatarko, Soil Scientist, gave a tour of the WERU wind tunnel facility to local Boy Scout Troop 76. This activity began with the group viewing the DVD titled "Soil Erosion by Wind and Its Control" followed by a short PowerPoint presentation covering the Dust Bowl, wind erosion processes and the dust storm of May 29, 2004. The group toured the laboratory where Tatarko showed them WERU research equipment and talked about Unit research. Finally they viewed a demonstration of erosion processes in the large wind tunnel. The activity lasted approximately 1.5 hours. Eighteen people attended the tour consisting of scouts, parents and scout leaders.

3. WERU Scientists Present Workshop at International Erosion Control Association Annual Conference. On February 20, Simon van Donk, Agricultural Engineer, and Gary Tibke, retired cooperating NRCS scientist, conducted a half-day workshop on the Wind Erosion Prediction System (WEPS) at the IECA Conference in Dallas, TX. They gave an overview of WEPS and taught how to build and run various WEPS projects including bare soil, roughness, wind barriers, vegetative cover, and different locations. Van Donk and Tibke concluded with a discussion about how WEPS can be modified to be more useful for construction sites. The main items mentioned in the discussion were: 1) WEPS should deal with elevation and steep slopes; 2) should be able to have barriers inside the field, not only at the edge of a field; 3) simulate the effect of construction equipment traffic on surface soil properties that affect wind erosion; 4) simulate the effect of construction mulch materials: rocks, blankets, hydro mulches, chemical treatments, etc.; 5) account for soil that is coming into a field (incoming saltation); 6) add the ability to plan for a bad year, probability analysis; 7) simulate vegetation establishment and competition among plant species with various seeding rates; and 8) use terminology that is understand by all participants. Most of the

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participants are responsible for compliance with environmental regulations on construction sites and wished that WEPS were available now for application to their wind erosion situations.

4. Customer Focus Meeting of the USDA-ARS Wind Erosion Research Unit (WERU) Held. On April 6, the customer focus group of the WERU met in Manhattan, Kansas, and expressed needs relating to wind erosion research. The customer focus group participants produced 18 general needs and rated them as high, medium, or low priority. WERU combined a few similar items and placed the combined needs under Unit's mission strategies - according to priority ranking to produce a report. It is not possible to address all of the indicated needs immediately. However, the expressed needs help to focus on those most beneficial. The report is a considered a living document subject to change as perceived needs and resources change. The Unit desires to partner with local, regional, national, and international research, technology transfer, regulatory, and educational organizations and land managers to accomplish its mission.

5. WERU Scientists Conduct Workshop and Present Seminars at Three Universities in China. In May, Larry Wagner, Agricultural Engineer, and Edward Skidmore, Soil Scientist, conducted WEPS Workshop for Sino-U.S. Joint Center for Soil and Water Conservation and Environmental Protection at Northwest A and F University, Yangling, China, toured wind erosion prone Ningxia Hui Province Autonomous Region, toured facilities and interacted with faculty/students at Beijing Normal and China Agricultural Universities in Beijing.

The purpose of the Workshop was to introduce WEPS to Chinese students and scientists, extend and verify applicability of WEPS outside the U.S. (China) and identify additional research needs. Fenli Zheng, Deputy Director of National Key Laboratory of Soil and Water Erosion and Dry Land Farming for the Loess Plateau, welcomed everyone to the workshop and opening remarks were made by Hou Xi, Vice-President of Northwest A&F University, Edward Skidmore, USDA-ARS, and Li Rui, Director of Institute of Soil and Water Conservation, CAS & MWR. Twenty-nine individuals participated in the workshop.

Beijing Normal University: Skidmore lectured on "Soil Erosion by Wind: Problems and Strategies for Coping" and Wagner demonstrated the wind erosion model, WEPS 1.0. Discussion of China wind erosion issues followed the presentations. One specific issue being addressed by Beijing Normal University researchers at a research station in Inner Mongolia was excessive soil loss from dirt roads in their grasslands region. The erosion is so severe that roads are abandoned when they become unnavigable and new roads are created adjacent to the abandoned ones. We concluded with a tour of their new laboratory wind tunnel facilities currently under construction.

China Agricultural University: Skidmore lectured on "Soil Erosion by Wind: Problems and Strategies for Coping" and Wagner demonstrated the wind erosion model, WEPS 1.0. Discussion of field wind erosion research being conducted at China Agricultural University followed. Specific projects discussed included: field studies on cropland under various residue management practices; measurement of soil loss by wind on the experimental sites. Their recently constructed portable wind tunnel is used to measure susceptibility to wind erosion on different field surfaces.

6. Scientists Visit WERU – June 13-17.

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Emmanuel Diaz Nigenda, an environmental engineering student with the National Autonomous University of Mexico in Mexico City visited WERU June 13-17. His research involves coupling the WEPS erosion submodel with the MCCM dispersion model and the MC5 weather simulation model. The goal of this research is to simulate the dispersal of dust emissions from the dry bed of Lake Texcoco. The purpose of his visit was to obtain training for the WEPS model and discuss temporal scales of his study as well as the parameterization and validation of his work. On June 15-16, Tom Hoffmann and Nikki Stefonik with Metro Wastewater Reclamation District (MWRD) in Denver visited WERU to obtain WEPS training. They intend to use WEPS as a management tool to control wind erosion on 52,000 acres of farmland to which MWRD applies bio-solids resulting from wastewater treatment.

7. WERU Scientists Participate in the USDA Air Quality Task Force Meeting. On June 20-22, Edward Skidmore, Soil Scientist, Larry Wagner, and Lawrence Hagen, Agricultural Engineers with WERU, gave an invited presentation to the members of the task force about the Wind Erosion Prediction System model and its application to air quality issues. In a follow-up "thank you" letter, Bruce Knight, Task Force Chair, stated: "The issue of atmospheric particulate matter concentrations and their relationship to agricultural management practices is of great interest to the Task Force. The considerable effort you have gone to in establishing causal linkages between the two will be helpful to us in pursuing our charge."

8. ARS and NRCS Scientists Conduct Workshop. On August 3, Larry Wagner, Agricultural Engineer, John Tatarko, Soil Scientist, Edward Skidmore, Soil Scientist, and Arnold King, NRCS Cooperating Scientist, presented a half day workshop on the Wind Erosion Prediction System (WEPS) at the Soil and Water Conservation Society (SWCS) Annual Conference in Rochester, NY. In their presentation they included several topics: 1) soil, water, and air quality as influenced by wind erosion; 2) development of wind erosion technology; 3) overview and demonstration of WEPS; 4) use of WEPS for conservation planning; 5) soil erosion by wind and its control (video); and 6) discussion.

9. WERU Demonstrates Field Wind Tunnel at Education Field Day. On the morning of September 8, John Tatarko and Hubert Lagae, WERU, participated in the Kansas State University, Agronomy Department's annual Kid's Field Day at the North Agronomy Farm. This field day attracted about 300 third through sixth grade students, teachers, and parents from the Manhattan area, including Manhattan, Riley, Junction City and Sheridan schools. Tatarko and Lagae's presentation consisted of a discussion of wind erosion problems, extent, and control using photographs and maps on a poster display. This was followed by a demonstration of wind erosion processes and control principles using the WERU portable wind tunnel. New items added to this year's presentation included small anemometers at the outlet end of the tunnel as well as a tower a few meters away, on which were mounted several BSNE catchers, a wind direction vane, and a large cup anemometer. The wind tunnel was as usual a big hit with the kids.

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Dr. John Tatarko sets up wind erosion display.

10. WERU Scientist Participates in International College on Soil Physics 1980-2005. After giving an invited lecture at Workshop on Physics of Desertification held at the Abdus Salam International Centre for Theoretical Physics (ICTP) Trieste, Italy, in 1980, Ed Skidmore, Soil Scientist, was invited to submit a proposal for a possible course in soil physics for scientists from developing countries. The Academic Board of the ICTP approved the proposal. Skidmore was ask to co-direct the first "College on Soil Physics" held in 1983 and all subsequent Colleges which have been held approximately every two years. In addition to co-directing the activity Skidmore gives several lectures on his ARS wind erosion research. To date more than 500 scientists from approximately 70 countries have participated in these soil physics activities held at ICTP. The College on Soil Physics is one of the longest continuous running programs at ICTP. In September, Skidmore again participated in the College on Soil Physics. His lectures dealt mostly with problems, processes, and control of soil erosion by wind and the Wind Erosion Prediction System (WEPS) developed by USDA - ARS scientists. Electronic copies of about 40 papers, Unit developed video on Soil Erosion by Wind and its Control, and reports of selected activities were distributed as a packet of information to activity participants. The preliminary list of participants included 74 names from about 30 countries. Lecturer contacts included Donald Gabriels, Roger Hartmann, (Belgium), Ildefonso Pla Sentis (Spain), Klaus Reichardt (Brazil), Otto Spaargaren (Netherlands), Miroslav Kutilek (Czech Republic), Giancarlo Ghirardi, Giorgi Filippo, Jeremy Pal (ICTP), Enrico Feoli, Marcello Fagliai (Italy), and Donald Nielsen (USA). Separate from the College on Soil Physics activity, Skidmore visited with Mohamed Hassan, Secretary General, Third World Network of Scientific Organizations (TWNSO) and the Executive Secretary of the Third World Academy of Science (TWAS). Hassan is interested in various aspects of wind erosion as it relates to physics of desertification.

11. Panel of Experts Review the USDA-ARS Wind Erosion Research Unit (WERU). On October 17-21, a panel of experts reviewed the WERU research program. Panel members included Lajpat R. Ahuja, USDA-ARS, Fort Collins, CO; Dale A. Gillette, NOAA, Raleigh, NC; Greg L. Johnson, USDA-NRCS Air Quality Program, Portland, OR; and William F. Schillinger, panel chair, Washington State University. The review addressed the relevance, scientific merit, capacity, and national/international leadership of WERU's research and developments. This report is based on the review and analysis of the scientific accomplishments, publications and current research program of WERU as described in the Briefing Book provided to the Panel, presentations by individual WERU scientists, interviews and discussions with ARS National Program Staff, Area Directors, Center Director, WERU scientists and staff, and numerous stakeholders, as well as visits to the WERU facilities. The stakeholders and the information provided by them are given in the detailed report which is available upon request.

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Expert panel members Lajpat R. Ahuja, William F. Schillinger, Dale A. Gillette, and Greg L. Johnson.

12. Manhattan and Mandan Scientists Collaborate. On October 24, Dr. Simon van Donk pooled resources with Mandan's Dr. Steve Merrill and the NGPRL research staff. Their focus was on using cropping systems information from Mandan for wind erosion prediction modeling. While in Mandan, van Donk also studied northern Great Plains crop agriculture, especially crop residue relations. He presented a seminar for NGPRL staff on his research on October 27.

13. WERU Scientists Participate in Joint International Crop and Soils Meeting. On November 6-10, sWERU scientists participated in the 2005 American Society of Agronomy/Crop Science Society of America/Soil Science Society of America (ASA-CSSA-SSSA) annual meeting in Salt Lake City, UT. Lawrence Hagen, Agricultural Engineer, presented a paper on "Estimated dust emissions from sediments in a confined disposal facility." Simon van Donk, Agricultural Engineer, presented a paper on "Comparison of measured residue cover with that simulated by the Wind Erosion Prediction System."

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Research Activities:

CRIS 5430-11120-007-00D

Particulate Emissions From Wind Erosion: Processes, Assessment, and Control

Project Leader: E. Skidmore

Investigators: E. Skidmore, J. Tatarko, L. Wagner, and L. Hagen

Full-Time Scientist Equivalents (Sys): 4.0

Start Date: 09/01/02

Term Date: 08/31/07

Problem: Wind erosion causes about 44 percent of the 2.13 billion tons per year of soil loss from U.S. cropland. In the Great Plains alone, about 5 million acres are moderately to severely damaged by wind erosion each year. Wind erosion physically removes the most fertile portion of the soil from the field. Some soil from damaged land enters suspension and becomes part of the atmospheric dust load. Dust obscures visibility, pollutes the air, causes automobile accidents, fouls machinery, and imperils animal and human health. Blowing soil also fills road and irrigation ditches; buries fences, reduces seedling survival and growth; lowers marketability of vegetable crops; increases susceptibility of plants to diseases; and contributes to transmission of some plant pathogens. Deposition of wind-blown sediments in drainage pathways and on water bodies significantly deteriorates water quality. Wind erosion continues as a threat to agricultural sustainability and environmental quality.

Objectives: The main goal of this project is to increase our understanding of wind erosion and dust emission processes and provide a scientific basis for development of prediction technology and control measures. Specific emphasis is placed on the continued development of a Wind Erosion Prediction System (WEPS).

Wind erosion's threat to sustainable agriculture is being resolved by 1) improving WEPS for cropland and extending it to range, forest, and disturbed lands, 2) increasing our understanding of particulate emissions from wind erosion processes, 3) coupling WEPS with appropriate databases to inventory dust emissions including PM-10 over large areas, and 4) developing new practices for reducing dust emissions from wind erosion and incorporating the findings into WEPS.

This is providing a more reliable science-based technology for improving erosion prediction; developing soil-, climate-, and crop-specific control strategies; and for assessing erosion damage and environmental impact. Beneficiaries from of this technology include State and Federal regulatory agencies, those making national resource inventories, conservation planners, those formulating policies relating to conservation reserve programs and global change, land managers, and in-effect all global inhabitants.

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Results and Impact:

1. Official Hand-Off of the Wind Erosion Prediction System (WEPS) 1.0 from ARS to NRCS. The latest and most cutting-edge model for forecasting wind erosion damage is a step closer to reaching growers and landowners in the wind-prone regions of the country.

Dr. Will Blackburn, ARS Director of the Northern Plains Area, hands a copy of WEPS 1.0 to Dr. Larry Clark, Deputy Administrator of the Natural Resources Conservation Service.

The system was developed and refined by scientists in the Center's Wind Erosion Research Unit. In a ceremony held in Manhattan, Kansas, on April 4, ARS officials transferred the erosion-predicting technology to the USDA's Natural Resources Conservation Service (NRCS), which will oversee its implementation across the United States. WEPS 1.0 can simulate weather, soil and crop conditions, and wind erosion on a daily basis. It can also project the emission of the tiny dust particles referred to as PM-10 that may pose risks to human health and the environment. Using WEPS 1.0, individual farmers will be able to formulate specific wind erosion control practices. The software can guide growers to the right approach—whether it's establishing a soil-stabilizing crop cover, establishing wind breaks and barriers or reducing soil's erodibility by appropriate tillage.

Goals for 2006, 2007, and 2008:

Specific tasks in 2006 will be to:

1. Execute plans to address customers' future wind erosion and air quality prediction needs including extending WEPS 2.0 to forest, range, and other disturbed lands and developing viable practices for reducing dust emissions from wind erosion.

2. Determine threshold friction velocities as a function of soil temporal properties, and determine size distribution (including PM10 and PM2.5) of eroding aggregates created by erosion processes (entrainment of loose soil, clod/crust abrasion, and breakage of saltation-size aggregates) on bare soils as a function of temporal and intrinsic soil properties.

3. Determine surface friction velocity as influenced by vertical and horizontal distribution of biomass.

4. Determine soil aggregate status as influenced by weather, intrinsic soil properties, land use, vehicular and animal traffic.

5. Couple WEPS with appropriate databases to inventory dust emissions including PM-10 over large areas.

6. Develop a procedure to simulate wind speed from limited data for use in WEPS (this activity is in conjunction with the Sino-Us agreement).

Specific tasks in 2007 will be to:

1. Develop new and evaluate viable practices for reducing dust emissions from wind erosion and incorporate findings into WEPS.

2. Determine best management practices (BMPs) to reduce the rate of roughness degradation.

3. Develop BMPs to maintain the crop residue's ability to reduce wind erosion.

4. Evaluate products to reduce dust emissions.

5. Concentrate on objectives and tasks on Project Plan 5430-11120-007-00D (termination date 08/31/2007) that are not yet fully accomplished.

6. Develop next OSQR project plan and start accomplishing tasks identified on next plan.

Specific tasks in 2008 will be to:

1. Conduct field-scale evaluation of quantitative process-level modules to evaluate management alternatives for semi-arid cropping systems.

2. Modify WEPS so that it can be used as a Dust Event Prediction Warning System (DEPAWS).

3. Combine wind erosion prediction and water erosion prediction models.

4. Determine what fractions of dust are PM 10 and PM 2.5 from different soil types.

5. Identify minimum data necessary to run WEPS.

Cooperative Agreements for This Project Include:

a. The Natural Resources Conservation Service, Washington, DC

b. The Department of Agronomy, Kansas State University, Manhattan, Kansas

c. The Department of the Army, Washington, DC

Summary of 2005 Publications/Patents:

1. Liu, L.Y., Skidmore, E.L., Wagner, L.E., Tatarko, J., and Hagen, L.J. Dune sand transport as influenced by direction, magnitude, and frequency of the erosive winds, Ordos Plateau, China. 2005. Geomorphology v. 67. p. 283-297.

2. Van Donk, S.J., Wagner, L.E., Skidmore, E.L., and Tatarko, J. Comparison of the Weibull Model with measured wind speed distributions for stochastic wind generation. 2005. Transactions of the ASAE. v. 48. p. 503-510.

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