Plant Biological and Molecular Processes
FY 2003 National Program 302 Annual Report

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Introduction

This program includes much of the Agricultural Research Service's fundamental research with plants that is necessary for practical advance but is too far upstream to provide direct solutions for specific agricultural problems. The research focuses on mechanistic understanding of specific plant processes and properties. The knowledge and tools developed can be used to improve functions and properties of crops. This program is divided into three components: Analysis and Modification of Plant Genomes (functional genomics, focusing on the molecular end of the research spectrum and technology for modifying plant genomes); Biological Processes that Determine Plant Productivity and Quality (mechanisms of plant growth and development, photosynthesis, productivity, and environmental responses that relate processes and attributes of the whole organism to their genetic and metabolic underpinnings and provide the context for molecular manipulations); and Mechanisms of Plant Interactions with Other Organisms (plant defensive reactions to pests and pathogens, emphasizing those that reduce the need for applied pesticides; interactions with beneficial organisms; secondary metabolism and products). Together, the results of the research approaches under this National Program provide a continuum of understanding of plant function from genes to phenotype (plant attributes and performance).

During 2003, there were many important discoveries and advances, some of which are described below. By no means do these selected accomplishments capture the important achievements of the entire research program. Instead, they highlight the type of activities carried out under this program and the type of benefits that result. The advances are grouped by program components.

Selected Accomplishments by Component

Component I. Analysis and Modification of Plant Genomes

Biosafety of genetic engineering: Limiting where and when transgene products occur. Many consumers demand measures to promote the biosafety of genetic engineering, and ARS is responding in several ways. One important goal is the confinement of genetically engineered gene products, when appropriate, to specific tissues of the plant or to specific times in the plant's development, rather than in the whole plant throughout its life. This specificity is provided by specialized gene promoters that respond to specific stimuli. At Beltsville, Maryland, research has identified promoters that respond to viral diseases. At Albany, California, ARS scientists have identified promoters that are specific for various tissues. At Kearneysville, West Virginia, ARS scientists have demonstrated that a leaf-specific promoter in apple trees does not allow expression of transgenes in fruits. At Madison, Wisconsin, a promoter has been developed that is specific for the "hull" (seed covering tissues) in barley. At Lubbock, Texas, ARS scientists have "taken apart" the process by which viruses take over plant gene expression and identified characteristics that make promoters effective. These studies are leading to the development of highly specific, yet effective, gene promoters which will limit genetically engineered products to only those sites within the plant and times when they are needed.

<u>Biosafety of genetic engineering: Improving the specificity of gene insertion</u>. In Albany, California, ARS scientists have tested a novel recombination system that enhanced the specificity of gene incorporation into the host genome. The system provides precise integration in a model test system, that minimizes disruption of the DNA, and the gene is heritable. This provides the basis for research to apply the novel system to crop plants. Also at Albany, California, ARS scientists have successfully tested a new system to "stack" separate genes end-on-end in the host genome, so that they will be incorporated together and be passed on to the next generation together. This stacking technology is expected to be broadly useful in creating plants with several desirable characteristics and having all the genes respond to the same genetic controls.

<u>Biosafety of genetic engineering: No more antibiotic resistance</u>. The European Union has adopted regulations that will prohibit genetically engineered materials that are resistant to an antibiotic. At Lubbock, Texas, ARS scientists have developed a simple procedure to replace the use of antibiotic resistance genes during genetic engineering. This new procedure will enable creation of transgenic plants without antibiotic resistance, and thus, in the future help to maintain exports of agricultural products to Europe.

Component II. Biological Processes that Determine Plant Productivity and Quality

<u>Understanding heat tolerance of crops</u>. Heat sensitivity, one of the major limitations to crop productivity, determines in part where crops can be grown successfully. ARS scientists at Phoenix, Arizona, showed that photosynthetic rate at high temperatures is controlled by heat sensitivity of the enzyme, *Rubisco activase*, which is necessary for plants to take up and incorporate carbon dioxide. Plants with different temperature tolerances have *Rubisco activase* sensitivities to temperature that mirror those of the plants. In related research at Urbana, Illinois, ARS scientists have tested other potential sites of heat damage to photosynthesis and found that those sites do not account for heat sensitivity. At Lubbock Texas, ARS scientists are describing molecular processes in plants that restore cell functions after heat damage. They have also identified mutations that reduce the plant's ability to protect itself against heat damage. The identification of the primary "subcellular" sites of heat injury is a major scientific advance that should enable breeders to improve crop productivity at high temperatures more rapidly.

<u>Managing lignin production in plants</u>. Ethanol production, although providing more than 1 percent of automotive fuel needs in the United States, still represents only a very small fraction of the demand for renewable energy. Cornstarch is a relatively high-value "starting material"for ethanol production; but utilization of low-value cellulosic sources, such as corn stalks, is hindered by the presence of lignin, which complicates ethanol production. Scientists at Albany, California, have now demonstrated that a regulatory gene in corn controls the amount of lignin deposited in the stalk. Plants with reduced levels of this gene make more lignin, and plants with

increased levels make less lignin. Manipulation of this gene offers the first chance to control the amount of lignin in stems or branches, thereby possibly providing a mechanism for efficiently using waste cellulosic materials for ethanol production.

Genetic basis for improved nutritional properties of foods. Fruits and vegetables contain many minerals, vitamins, and other compounds that are needed for health. ARS is pursuing several ways to improve the nutritional quality of these foods. At Ithaca, New York, ARS scientists have focused on several natural mutations that increase concentrations of lycopene and other carotenoids in tomato and on a gene that stimulates ripening and development of flavor and nutrient compounds. In Houston, Texas, ARS scientists found that a broad spectrum of genetic lines of pea have a 10-fold range of essential mineral concentrations, in some cases considerably higher than the standard garden pea. In both cases, these discoveries can form the starting point for breeding more nutritious vegetables. In Beltsville, Maryland, ARS scientists have genetically engineered a calcium-binding protein into potatoes and shown that it can be useful in increasing the calcium content of this widely consumed food, which is deficient in calcium. In Oxford, Mississippi, ARS scientists, in cooperation with University of Idaho scientists, genetically engineered blueberries to contain high amounts of resveratrol, believed to be a dietary cancer preventative. The next steps in improving these fruits and vegetables are to test for bioavailability of the nutrients and to breed for higher nutrient levels using those genetic lines with increased bioavailable nutrients.

Component III. Mechanisms of Plant Interactions with Other Organisms

Identifying disease resistance genes in crop plants. Modern genetic methods make identification, modification, and utilization of disease resistance genes much faster than before. ARS scientists are very active in identifying, locating, and modifying resistance genes so they can be introduced into new varieties. Examples include the following: resistance to bacterial angular leaf spot disease in strawberry (Beltsville, Maryland); resistance to post-harvest decay organisms in peach (Kearneysville, West Virginia); resistance to late blight in potato (Madison, Wisconsin); resistance to various pathogens in papaya (Hilo, Hawaii); resistance to Sclerotinia blight in peanut (Stillwater, Oklahoma); resistance to blast in rice (Stuttgart, Arkansas, and Beaumont, Texas); resistance to soybean cyst nematode in soybean (Beltsville, Maryland); resistance to Fusarium head blight in barley (Madison, Wisconsin and Fargo, North Dakota); wheat (Albany, California, and Fargo, North Dakota); and resistance to wheat stripe rust (Pullman, Washington). The resistance genes, which include those introduced by both breeding and genetic engineering, will protect the next generation of crop varieties to be used in American agriculture.