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Highlights of 50 years of crop utilization research conducted at four regional laboratories of the United States Department of Agriculture

United States Department of Agriculture

Agricultural Research Service

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Always Something New

A Cavalcade of Scientific Discovery

Hubert W. Kelley

Highlights of 50 years of crop utilization research conducted at four regional laboratories of the United States Department of Agriculture

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Copies of ***Always Something New*** are available from an ARS regional research center convenient to you.

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November 1993

Contents

[redacted]

Name Changes

During the last 50 years, the regional laboratories have operated under several different names, while performing the same functions and remaining in the same buildings in New Orleans, Louisiana; Albany, California; Peoria, Illinois; and Wyndmoor, Pennsylvania. Since 1979, each has been known as a regional research center, and for purposes of clarity and consistency, this is the name used most frequently in this book to identify each of the four research facilities. To avoid monotony and redundancy, the Western Regional Research Center, for example, is also referred to by its initials (WRRC), or as the Western center, or as the Western or Albany lab or laboratory. As 1990 ended, the Northern Regional Research Center in Peoria was once again renamed by Congress. While it is identified in this book by its more familiar name or the initials NRRC, it will be known in the future as the National Center for Agricultural Utilization Research (NCAUR). All four centers, together with a fifth and newer center in Athens, Georgia, continue to be a part of the Agricultural Research Service, the principal scientific research agency of the U.S. Department of Agriculture.

The inside and outside of USDA's four regional offices are much like that of the Southern Regional Laboratory at New Orleans pictured here.

Introduction

It is easier to explain what ***Always Something New*** is not than what it is. It is not a chronological history. It does not attempt to be a complete record of discovery and invention at the four regional research laboratories. It is not an overview; the scientific landscape it traverses is far too broad and diverse to permit a single focus on events. Most certainly, it is not a *Who's Who* of accomplishment, since it rarely credits a researcher by name. If the imagination can be stretched enough to consider the regional centers as families, the book can be considered as a family album, a reminiscence of memorable and important events during the last 50 years. In its concluding chapter, it also outlines several of the research challenges ahead for the centers as they begin their second half century.

Partly because of the sheer volume of important research conducted at the four laboratories since 1940, few people, including many scientists working at the regional labs today, fully appreciate the magnitude of what has been accomplished. Researchers at the centers took the lead in modernizing several industries saddled with obsolete processes and machinery, including cotton processing and the manufacture of leather, turpentine, and maple syrup. They improved many agricultural products, including cotton and woolen fabrics and soybean oil, making them much more acceptable to consumers. They made the critical discovery that created soft vinyl plastics.

They developed many new food products from farm surpluses, including frozen concentrated orange juice and apple juice and dehydrated potato flakes. They performed much of the crucial early research that made frozen foods popular, and they were instrumental in launching the soybean oil industry. They expanded U.S. exports by making domestic soybeans and wheat flour acceptable to Asian markets; they created nutritious food supplements for the humanitarian Food for Peace Program.

Scientists at the regional labs made enormous contributions to human health and food safety. During World War II, they made possible the mass production of penicillin and the many antibiotics that followed. Later, they helped synthesize vitamins, rutin, cortisone, and other pharmaceuticals. Their research made it possible for people with lactose intolerance to drink milk, and they developed an extender for human blood that saved uncounted American lives in Korea. In recent years, they have become authorities on detecting and preventing many food contaminants.

Researchers conducted several exhaustive and rewarding searches for plant sources of new drugs and oils for food and industrial use. They screened and studied thousands of microorganisms, looking for (and finding) microbes useful to industry and medicine. They also established one of the most complete collections of microorganisms in the world (see p. 134).

They solved problems of agricultural waste disposal that threatened the future of whole industries, including processors of fruits and vegetables and dairies and leather manufacturers. They created a host of nonfood products from farm commodities, including a thirsty compound called Super Slurper and biodegradable plastics.

They made many basic discoveries about the chemistry of farm commodities, and they pioneered the study of flavors and aromas. They patented hundreds of inventions and processes, many of which were adopted by industry. Several were used for a time, only to be supplanted by similar compounds made from cheap petroleum. Petrochemicals, in fact, have been the chief competitors over the years of chemicals made from agricultural commodities. Higher oil prices and a national policy of reduced reliance on oil imports could alter this picture in the future.

In reviewing the accomplishments of the regional centers, it is difficult to see how their record could have been realized except with Federal funding and direction. In most instances, business and industry are unable to afford research of the kind carried out at the ARS laboratories. Further, much of their research affects whole regions or the entire Nation, making it inappropriate for conduct by State experiment stations. Federally funded agricultural research, when carried out with the advice and cooperation of growers, processors, and industry, seems most productive of results.

Gambling on Science

Congress in 1938, desperate to find ways to dispose of surplus crops and end a chronic farm depression, authorized the U.S. Department of Agriculture to build and staff four regional research laboratories. Their purpose would be to find new chemical and technical uses and markets for farm commodities, particularly those, like wheat, cotton, milk, and potatoes, with "regular or seasonal surpluses."

Authorization for the laboratories formed a relatively small part of the omnibus 1938 legislation—the Agricultural Adjustment Act of 1938. The law was enthusiastically described by Secretary of Agriculture Henry A. Wallace as "a new charter of economic freedom for farmers." It provided for marketing controls, acreage allotments, soil conservation, and loans and crop insurance. One detailed history of the legislation, under the subhead of "other provisions" of the 1938 Act, devotes only half a sentence to the creation of the regional research laboratories.

The laboratories might not have been authorized at all were it not for the influence of the chemurgy movement. (The word means the development of new industrial products from organic raw materials, especially farm products, and the term was much in vogue in the 1930's.) In 1935, a group of scientists and industrialists formed a Farm Chemurgic Council, to be headed for many years by Wheeler McMillen, longtime editor of *Farm Journal*. The Council had the support of such influential Americans as Henry Ford, Irenee duPont, and Dr. Karl T. Compton, who made sure that their message reached Congress. That message was that, through research, practically unlimited opportunities existed for the creation of new products from farm commodities.

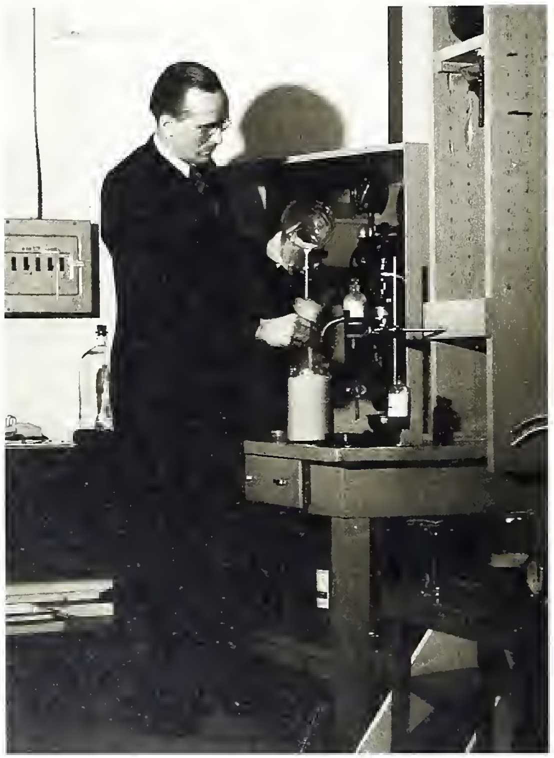
New scientific and engineering tools promised to change the direction of agriculture.

McMillen in particular felt strongly that chemurgy's time had come. He wrote: "During the 1800's, organic chemistry began to be important, and Mendel's law, the basic principles of plant genetics, became known. The early part of this century saw the rising application of power to agriculture. These three relatively recent developments in chemistry, genetics, and engineering have made chemurgy possible. They have provided a wholly new set of tools for moving agriculture forward in new directions."

Three of the first three directors of the regional laboratories were (left to right) D. F. J. Lynch, Southern; T. L. Swenson, Western, and O. L. May, Northern.

Congress was also encouraged by the excellent track record of research of the U.S. Department of Agriculture. With limited funds, its scientists had made many significant scientific discoveries since USDA's creation during the Civil War, and several small research facilities were proving their value in developing new products from farm commodities.

The most potent stimulus for Congressional action, however, were the crop surpluses themselves. Overproduction had been a vexing problem since World War I—a problem worsened by the loss of foreign markets for U.S. crops in the early stages of World War II. In the 1920's came inflation, followed by deflation and a crash in commodity prices. Also contributing to surpluses and low farm income was the growing productivity of the American farmer. Mechanization and better crop varieties year after year increased farm output per acre, per hour of labor, and per animal unit.



At 32, the youngest of the first lab directors was Percy A. Wells, who headed the ERRC until 1969. Wells attended the 50th anniversary ceremonies at the laboratory.

All these reasons—the crop surpluses, USDA's proven record in research, and the influence of the farm chemurgy movement—led Congress to seek help in reducing surpluses from scientists and technologists. The original proposal for a research laboratory came from Sen. Theodore G. Bilbo of Mississippi, whose primary concern was the cotton surplus. He negotiated with other senators with different commodity interests, and they agreed to authorize laboratories to explore new uses for specific crops in each of four regions. Briefly, that is how the research centers began.

After passage of the 1938 Act, Congress directed USDA to conduct a survey to determine the most promising avenues for research and to recommend locations for each of the four laboratories. Results of that survey, which was carried out by the four scientists selected to head the labs, were published in 1939 in a 429-page report (Senate Document No. 65, 1st session, 76th Congress). It is a remarkable report, not only for its lucidity and breadth, but also because it was prepared in less than 9 months. Members of the staff reviewed 10,000 research projects and visited 1,300 institutions with an interest in chemurgical research. They included 200 colleges and universities, State experiment stations, farm organizations and trade associations, and no fewer than 1,100 industrial research laboratories. From this multitude of sources, the staff was able to put together a comprehensive picture of current research in agricultural commodities. More importantly, they were able to present proposals for additional research on practically every type of crop in the United States, from corn and wheat to olives and papayas.

The scientists also visited 80 separate sites proposed for the four laboratories, considering such practical matters as accessibility to transportation, housing and living conditions, and availability of adequate utility services. They also looked at proximity to agricultural processing industries. The staff recommendations were turned over to the USDA administration, and the four sites were selected. They were: the Philadelphia area for the eastern lab; Peoria, Illinois, for the northern lab; New Orleans for the southern lab; and the San Francisco Bay Area for the western lab.

The commodities to receive initial attention by the four research centers were designated as follows: southern area—cotton, sweetpotatoes, and peanuts; northern area—corn, wheat, and agricultural waste products; eastern area—apples, potatoes, milk products, vegetables, and tobacco; and the western area—fruits and vegetables, wheat, potatoes, and alfalfa. The authors of the survey report said they expected the list of commodities to grow in time, a prediction that came true almost as soon as the laboratories opened their doors.

Congress appropriated $4 million to build and equip the laboratories, the funds to be divided equally among the four. Sites were secured quickly. In the East, a former horse farm was purchased in Wyndmoor, just outside Philadelphia. In New Orleans, the site was a swampy part of City Park, near Bayou St. John. It was given to USDA by the municipal government. The lab at Peoria received for the price of $1 a tract of land in a residential area. The donor was Bradley Polytechnic Institute, later to become Bradley University. Finally, the western lab obtained its real estate in Albany, California, next door to Berkeley. Part of the land was a gift of the University of California.

The design of the newly constructed Western laboratory in 1940 was practically identical in design to those of the other three. The Western lab today (below).

Building designs were the work of USDA architects and were practically identical for all four laboratories. Each eventually was to be a U-shaped, four-story structure, with certain areas left wide open enough to construct industrial pilot plants. These were among the first laboratories in the country built solely for research, and other institutions, both public and private, were to copy parts of their design in the years that followed.

Contracts were let quickly, and by 1940, all four research facilities were under construction. By the end of 1940 or early 1941, the buildings had been completed and equipped, the first scientists employed, and research begun.

In today's age of public relations hype, official enthusiasm for the new laboratories in 1940 seems remarkably restrained.

Dr. Percy A. Wells, first head of the Wyndmoor lab and the only one of the initial quartet of directors to live to see his laboratory's 50th anniversary, admits that his new facility was not without flaws. "Within an hour," he recalls, "employees discovered that all the restrooms lacked toilet paper holders. This omission was brought forcibly to my attention. After a long and somewhat ludicrous telephone conversation, I finally convinced the purchasing people in Washington that there wasn't time to advertise and seek bids from contractors. Eventually I outreasoned or outshouted them. Within 48 hours, we had our toilet paper holders and our employees settled down to work."

For administrative purposes, the four laboratories formed part of a Bureau of Agricultural Chemistry and Engineering, with an assistant chief of the Bureau as their immediate supervisor. He remained in Washington, D.C.

In today's age of public relations hype, official enthusiasm for the new laboratories seems remarkably restrained. An article in *Farmers in a Changing World*, the 1940 Yearbook of Agriculture, notes in a single brief reference to the four laboratories: "The market for farm products is to be held—and expanded wherever possible—by aggressive use of...science and technology...That, at least, is the purpose [of the labs]. The desired result may not be attainable, but the game is not to be lost by default, at any rate."

Funding the Labs

The original 1939 appropriation of about $4 million for the four regional centers stayed approximately level until after World War II, when funding slowly began to climb. In 1950, the four labs shared funds of $8.3 million; in 1960, $16 million; in 1965, $29.9 million; in 1975, $41.4 million; in 1980, $60 million, and in 1991, about $64.7 million. Each individual lab's percentage share of the funds varied from year to year, depending on the cost of its projects at any given time. By all estimates, the research has paid for itself many times over.

Also restrained was Secretary Wallace, a scientist himself, who spoke when laying the cornerstone of the Western laboratory in 1939. He cautioned that "results from the research program are likely to be slow in coming. We must think, not in terms of weeks or months, but of years and decades." He added, however, that the research program "does have constructive possibilities."

More enthusiastic (and a better forecaster, as it turned out) was the first director of the laboratory at New Orleans, Daniel F.J. Lynch, who in 1939 told a scientific group: "One important line of attack (on the surplus problem) is by means of research...a comprehensive, concerted, closely knit program of research...carried on with the specific aim of finding new and extended uses for farm commodities. We believe that research of this nature will pay (not immediately of course—that would be too much to hope for) but more and more with the passing of each year. We believe, moreover, that such a program is long overdue."

Penicillin and the War Years

As it turned out, it was unnecessary to wait as long as the Secretary of Agriculture had predicted for exciting and meaningful research results. The four regional laboratories had been in operation for only about a year when, on December 7, 1941, Japan attacked Pearl Harbor. On December 8, the United States declared war on Japan, and the goals of the researchers were soon altered to meet urgent needs of the military. But the story of wartime research actually began several months earlier. On July 9, 1941, Percy Wells, on detail from the Eastern lab to Washington, received two visitors from war-beleaguered England. They had with them a small but valuable package. The Britishers were Howard Florey, a future Nobel Laureate, and Norman Heatley, an Oxford University bacteriologist, and their package contained a small amount of penicillin, a drug unfamiliar to Dr. Wells. The two scientists wanted U.S. help in mass-producing it.

Penicillin was discovered in 1928 by Alexander Fleming at St. Mary's Hospital in London. He observed that a plate culture of *Staphylococcus* had been contaminated by a blue-green mold and that colonies of bacteria adjacent to the mold were being dissolved. Curious, he grew the mold in a pure culture and found that it produced a substance that killed a number of disease-causing bacteria. It was still effective, he found, when diluted as much as 800 times. The mold was eventually identified as *Penicillium notatum*. Naming the substance "penicillin," Dr. Fleming in 1929 published the results of his investigations, pointing out that his discovery was relatively nontoxic and might well have therapeutic value if it could be produced in quantity.

Until 1939, penicillin was almost forgotten. Then Florey and three colleagues, searching for better infection fighters as Great Britain faced the imminent threat of war with Germany, began work to see if they couldn't develop penicillin for medical use. By 1940, with war a reality, they had succeeded in converting penicillin into a stable, dry, brown powder. By 1941, the team

During World War II, Andrew J. Moyer, a chemist at the Northern lab, developed the industrial process—deep vat fermentation—that made mass production of penicillin possible. The technique was subsequently used to produce other antibiotics, vitamins, and other drugs and chemicals.

of scientists became convinced that if penicillin could be produced in quantity, it could be invaluable in preventing infections in war casualties. Unfortunately, hard-pressed British drug manufacturers were unable to undertake the necessary research.

That was the problem that Drs. Florey and Heatley brought to the United States in the summer of 1941, and USDA's Dr. Wells promptly directed them to the Northern laboratory in Peoria. Several researchers there, he assured them, were experienced in industrial fermentation and in growing molds. Work on the project began on July 14. By November 26, 1941, Andrew J. Moyer, the lab's expert on the nutrition of molds, had succeeded, with the assistance of Dr. Heatley, in increasing the Oxford yields of penicillin 10 times.

. . . Peoria researchers soon made another breakthrough. Searching for a superior strain of Penicillium, *they found it on a moldy cantaloupe from a local market.*

What Moyer had done was to grow the mold in a medium that included corn steep liquor, an inexpensive (nonalcoholic) byproduct of the wet corn milling process. Inclusion of the steep liquor, which was full of nutrients, provided a better growth medium then any tried in England. Dissatisfied, Moyer experimented until he had improved the medium with the addition of milk sugar, and *Penicillium* growth doubled again. Moyer also used deep vats to grow the cultures; his innovations with submerged culture fermentation became the basis for many industry practices to come. Results were so encouraging that Robert D. Coghill, head of NRRC's fermentation division, met in New York that winter with representatives of four major U.S. drug companies, who agreed to attempt large-scale production of penicillin. The meeting was held 8 days after the United States entered the war. By the end of 1942, 17 U.S. firms were working on penicillin.

In March, 1942, only enough of the drug was available to treat a single case. But the Peoria researchers soon made another breakthrough. Searching for a superior strain of *Penicillium*, they found it on a moldy cantaloupe from a local market. Named *Penicillium chrysogenum*, it was made available to the drug companies and greatly increased production of the antibiotic. Thanks to the combined efforts of many people, penicillin was available in quantity by June 6, 1944, to treat Allied soldiers wounded on D-Day.

In the years that followed the pioneer work in Peoria, new and better strains of penicillin were discovered, manufacturing techniques were improved, and yields were increased several thousand times. But years later, in 1970, George E. Ward, a member of the USDA research team, put the Peoria contributions in perspective in *Advances in Applied Microbiology*: "Hundreds of new antibiotics have been discovered...about 20 have had sufficient merit to justify their industrial production...Corn steep water is used in most media and submerged culture methods similar to those developed for penicillin are usually employed."

In 1987, Dr. Andrew Jackson Moyer was inducted posthumously into the National Inventors Hall of Fame in Arlington, Virginia. He was cited for his work in growing *Penicillium* mold in deep fermentation in corn steep liquor and milk sugar. He was the first inventor to be inducted for achievements in government research, and he joined such other prominent members of the Hall of Fame as Thomas A. Edison, Luther Burbank, and the Wright Brothers.

Other wartime research at the four regional laboratories, while less dramatic than the penicillin story, also proved productive. Several projects laid the groundwork for important postwar discoveries to come. Many new or improved products were needed for the war effort, and much of the work of the scientists was classified. They continued to work with agricultural materials, including possible new sources of rubber. At the Eastern lab, fruit aromas and flavors were captured in fruit essences, which, while not quite essential to the war effort, did help improve drinks and jellies for the crews of U.S. submarines.

Wartime Rubber Research

Natural rubber comes from the plant *Hevea brasiliensis,* a native of the Amazon Valley of Brazil. In 1876, its seeds were planted in a greenhouse near London, and the seedlings grown there were transplanted to plantations in Southeast Asia, the source of most U.S. rubber imports. During World War II, when Southeast Asia was overrun by the Japanese, rubber supplies to this country were cut off. The United States was forced to find other sources of rubber or risk losing the war.

The most promising source was Buna S, a general-purpose synthetic rubber resulting from U.S. and pre-war German research. It was produced from butadiene (a petroleum derivative) and styrene (produced from coal tar or petroleum). The U.S. Government built plants to produce Buna S and the styrene and butadiene to supply them. Rubber and chemical industries ran the plants and made the rubber.

The project succeeded. When the United States entered the war, this country was producing only about 18 million pounds of synthetic rubber a year. By the end of the war in 1945, production capacity had jumped to about 2 billion pounds a year, an incredible achievement and one essential to the Allied victory. The Government sold its synthetic rubber manufacturing plants to private companies in 1945.

A major contribution to the development of Buna S was made by scientists at the Eastern lab. Soap made from inedible grades of animal fats was the emulsifier used to manufacture synthetic rubber. In the critical year of 1943, wide variations in the rate of rubber formation indicated that unknown chemicals were retarding the process. The slowdown was most pronounced when soaps from low-grade tallow and grease were used, but excluding them failed to correct the problem. Eastern lab researchers found that two fatty acids—linoleic and linolenic—were responsible for slowing the rubbermaking process. Since both were polyunsaturated acids, partial hydrogenization of the fats (similar to a process for making margarine) remedied the situation. The ERRC also developed a sensitive method for detecting the presence of very small amounts of the two fatty acids. The technique proved useful, not only in the synthetic rubber industry, but also in carrying out subsequent research on fats and oils.

Three million pounds of natural rubber were made during World War II from U.S.-grown guayule, a desert plant.

While carrying out its crash program to make synthetic rubber, the Government also conducted an intensive search for rubber-producing plants that could be cultivated in the United States. *Hevea,* still the best source, wouldn't grow outside the Tropics and was unproductive even in Florida. Several promising plants were studied and tested by the regional laboratories, including goldenrod, guayule, and Russian dandelion. The latter plant, which was investigated at the Eastern lab, had been discovered in eastern Russia in 1929 near the Chinese border. In early 1942, two sacks of Russian dandelion seed were flown into the United States, and 600 acres were planted as an experiment in Michigan and Minnesota. Scientists found that the dandelions could produce rubber in 15 months or less and could be grown in most parts of the United States. A process for extracting rubber from the plant was developed by Eastern lab researchers, and enough rubber was produced to permit the fabrication of experimental car and truck tires. They proved of high quality. Research stopped, however, when the Government's Emergency Rubber Project was terminated in 1944. At that time, processing costs were not competitive with either *Hevea* or the new synthetic rubbers.

Another rubber-bearing plant studied was goldenrod, a source that had aroused the interest years before of Thomas A. Edison. Of all the alternatives to *Hevea* examined by USDA, however, the plant with the highest rubber content was guayule, a perennial desert shrub and a member of the sunflower family. After 4 years of growth under favorable conditions, the rubber content of a guayule plant will run as high as 20 percent. During World War II, as part of the emergency rubber project, 3 million pounds of guayule rubber were produced. After the war ended, with imports of natural rubber restored from Southeast Asia, work on the less cost-effective guayule, as well as on Russian dandelion, was dropped. Synthetic rubber, however, was here to stay. (See p. 94 for the story on domestic rubber research after the war.)

The Southern lab came up with mildewproof and rotproof fabrics for use by troops in the South Pacific and in improved cotton bandage. At the request of the U.S. Army, the Western lab mounted a large-scale project to dehydrate fruits and vegetables, not only to preserve them but also to decrease the weight and bulk of military rations. Dehydration proved successful for many products, including potatoes, eggs, and milk. Prepackaged soups and stews were compressed into small packages for shipping.

During the war years, "nobody watched the clock, nobody counted the hours. Like the rest of the Nation, we were committed to winning the war in the shortest possible time—and nothing else seemed to matter."

In the Northern lab, a batter process for separating starch and gluten from low-grade wheat flours was developed after starch from corn was diverted to increase the production of industrial alcohol. The process provided wheat starch to meet demands for sweeteners when beet and cane sugar were scarce. (In the late 1950's, NRRC improved the batter process to reduce the amount of water required to separate the starch.) This process formed the basis of the wheat gluten industry today. In other wartime research in Peoria, wheat replaced corn in the production of industrial alcohol, with the process tested in a converted whisky distillery.

One scientist recalled that during the war years, "nobody watched the clock, nobody counted the hours. Like the rest of the Nation, we were committed to winning the war in the shortest possible time—and nothing else seemed to matter."

Cotton Goes to War

Guncotton, the nitrocellulose explosive used to fire shells from big Navy guns, is made in part from cotton linters, the short fibers that cling to cottonseeds after the first ginning. As America's involvement in World War II began, the military foresaw a shortage of linters, but noted that there was a surplus of long cotton fibers. SRRC technical people went to work to transform long fibers into fuzzy short ones. They developed a machine to cut the cotton into short lengths, but found it could chop up the fiber faster than they could supply it—350 pounds of cotton a minute. So SRRC engineers invented a machine that could tear a mass of cotton apart and feed it in a thin, even sheet to the cutting disks. The high-speed process worked.

As it turned out, the artificial linters were never needed by the Navy, but the experimentation that went into the machines in New Orleans wasn't wasted. It led after the war directly to development of the granular card, an innovative machine for disentangling cotton fibers prior to spinning. It turned out to be one of the most important inventions for cotton processing.

In much the same way, wartime research to develop better cotton bandages led after the war to commercialization of stretch cottons. And a process for making oil-repellent fabrics, called for by the Army Chemical Warfare Service to protect military clothing from liquid chemical weapons, was later used by the Air Force for the clothing worn by rocket handlers who worked with liquid missile fuels.

One of the oddest discoveries, which appeared to have no application at the time, came about at the New Orleans lab during research to make firehoses out of treated cotton instead of linen. To prepare a cotton that would swell like linen when wet, researchers tried attaching hydrophilic, or water-loving, molecules to the cellulose chain of cotton.

Years later, a scientist on the project recalled: "We experimented using strong solutions of reactants to treat the cotton fabric. Then we left it to wash in running water. But when we came back to see how our product was doing, there was nothing left to inspect. The fabric had disintegrated and gone down the drain."

Eventually, however, a use was found for the disappearing cotton. In one manufacturing process, a machine makes lace by embroidering it on a backing cloth. What was needed was an inexpensive cloth that could be dissolved when no longer needed, leaving undamaged lace behind. The SRRC chemist reactivated his old experiment and found that cotton backing for the lace would dissolve readily in water containing alkali. The application led to production of millions of yards of cotton-backing cloth for lacemakers.

Midstream Changes and Corrections

In the 50 years since the regional laboratories began, they have been subjected to more than a few reorganizations, reviews, studies, examinations, and changes in direction. These have reflected changes in the agricultural and international situation, plans to increase governmental efficiency and effectiveness, and differing views among scientific and political leaders on proper goals for Federal research. The laboratories have, after all, carried out their work with public funds under 10 different administrations.

In their early years, the laboratories formed part of the Bureau of Agricultural and Industrial Chemistry, one of several scientific bureaus within the Department of Agriculture. On November 2, 1953, as part of a sweeping reorganization of USDA, the functions of the Bureau were transferred to a new agency, the Agricultural Research Service (ARS). Other scientific bureaus in the Department also disappeared as organizational entities at the same time, an extremely controversial move. An administrator, B.T. Shaw, was appointed to head ARS, which now included the four regional research centers. Except for the years 1978-81, when Agricultural Research formed part of a parent organization, the Science and Education Administration, the four labs, along with many other research facilities, have been a part of the Agricultural Research Service.

In 1957, progress at the four centers was reviewed by a Commission on Increased Industrial Use of Agricultural Products. This bipartisan group included four representatives of agribusiness and one agricultural educator. Its staff, which in a report to Congress recommended ways to increase industrial use of farm products, was headed by Wheeler McMillen of *Farm Journal*, the spokesman for the chemurgy movement. The staff also included several USDA research scientists.

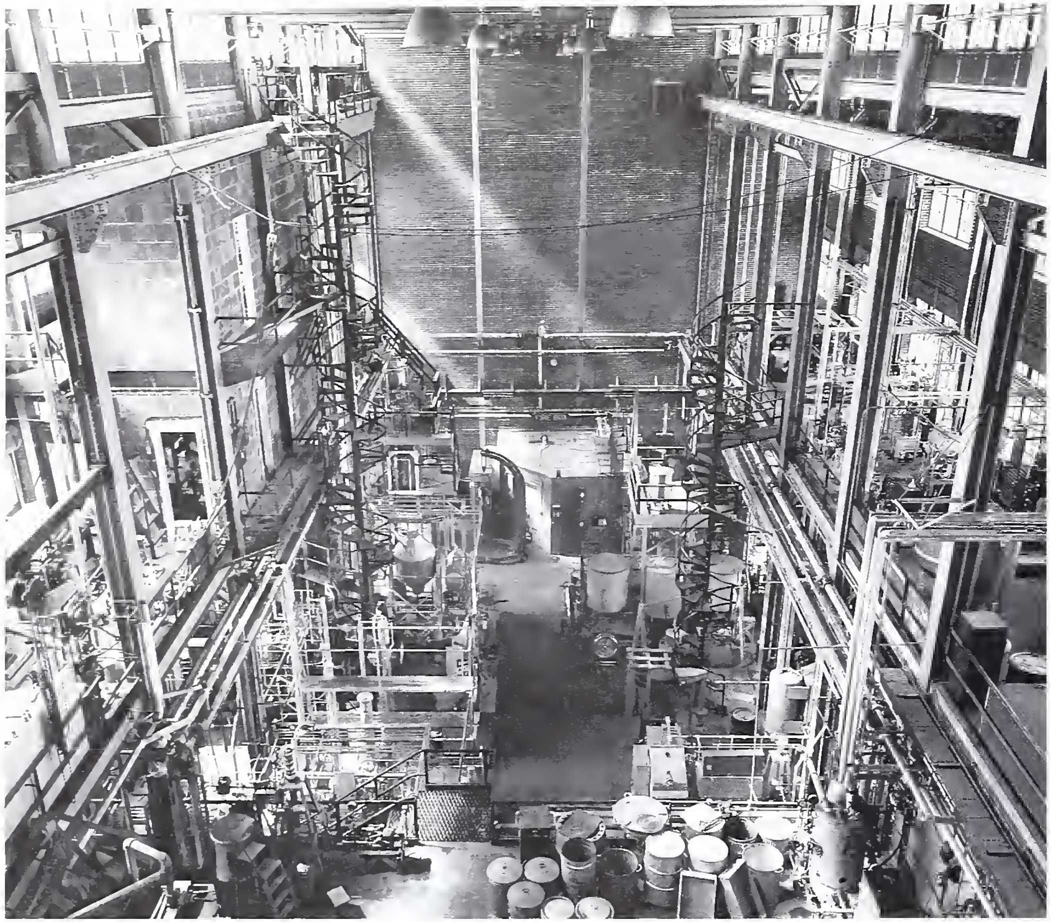
The report (Senate Document No. 45, 1957) identified "four main needs" to develop profitable industrial markets for products using surplus crops. Briefly, they were: (1) a sharper sense of the urgency of the industrial utilization approach; (2) greatly expanded fundamental and applied research; (3) scholarships, grants, etc., to train more scientific talent to work on "the neglected field" of farm product research; and (4) financial incentives for industry to try out and develop new products or processes.

While Congress took no action on most of the Commission's recommendations, its arguments in favor of more fundamental research helped lead, beginning in 1957, to the creation of 16 so-called pioneering laboratories within the Agricultural Research Service. Several of these basic research facilities were located at regional research centers.

Sixteen "pioneering" laboratories were created in 1957 to focus on basic research.

In 1960, an intensive appraisal of Federal-State farm research was completed by a Committee on Research Evaluation (CORE). The CORE group was headed by George W. Irving, Jr., then

Reporting in 1966 on their labs' first 25 years of research were (left to right, back row) R. J. Dimler, NRRC director; C. H. (Hap) Fisher, SRRC director; (seated) Percy Wells, ERRC director; Fred R. Senti, deputy ARS administrator for utilization; and M. J. Copley, WRRC director.



The buildings were large enough to permit construction of pilot plants within the walls so that new processes could be tested for feasibility before being adopted by industry.

head of ARS utilization research and development and later named as the agency's second administrator. Among other things, the CORE report stated that research to develop new crops and to increase efficient utilization of agricultural materials should be expanded more than crop production research. The scientists foresaw continued surpluses, high farm production and marketing costs, and lower farm prices. What was badly needed, they said, were new uses for surplus products and increased farm exports.

Value of the achievements in the mid-sixties was estimated at something over $6 billion—20 times the $309 million spent by the labs during their first 25 years.

In 1966, ARS conducted a review of accomplishments of the regional laboratories during the first 25 years of their existence. The reviewers found that 109 products and processes had been commercialized. Another 28 showed potential for application, and 26 represented major contributions in basic research. Value of the achievements in the mid-sixties was estimated by ARS leadership at something over $6 billion—20 times the 309 million dollars spent by the labs during their first 25 years. Then as now, the rate of commercialization of research project exceeded the national norm for all private and public research.

The same 25 years—1941-1966—were examined in a Ph.D. thesis at the University of Georgia, by Harold B. Jones, Jr., of USDA's Economic Research Service. Jones found that 9 percent of the projects undertaken by the regional labs by 1966 had produced an economic return. This figure compared favorably, he said, with returns on food industry research. Jones also estimated that research results had paid off at the rate of 20 to 1 or better, a very satisfactory economic return.

In 1967, a fifth utilization laboratory was added at Athens, Georgia, and the physical plant of the initial four labs underwent improvement. Most extensive was the addition of a third research wing in Peoria, changing the configuration of the NRRC building from a U-shape to a W.

During the 1970's, the international agricultural picture changed abruptly, with serious effect on the work of the regional centers. Disastrous harvests in many parts of the world sharply reduced surpluses worldwide. New national priorities focused on such areas as food safety and control of pollution. Restrictions in the labs on conducting preharvest research were relaxed and researchers carried out more projects in the areas of crop improvement and pest control.

This emphasis continued for several years. A revised program plan set forth by the Agricultural Research Service in 1982 included among its research goals more attention to resource conservation, improved food safety and quality, and more efficient processing, distribution, and marketing of food and agricultural products to users.

As the decade of the nineties began, however, the direction for research in the four centers began to change once again. The appropriation for the Agriculture Department for fiscal year 1990 directed USDA to move toward an annual level of at least $50 million a year for regional center research on "new nonfood uses for traditional food commodities such as wheat, corn, and soybeans..." After 50 years, the four regional centers were charged once more with research goals almost identical to those in the original 1938 Act. The wheel had come full circle.

Frozen Foods

Until frozen foods came along, there had been no major innovation in preserving food since the early 19th century, when Nicolas Appert, a French candymaker, invented canning. More than a century later, in 1925, Clarence Birdseye, an American inventor, quick-froze fish on a refrigerated moving belt and started a new industry. Large-scale commercial food freezing began a few years later, when a major processor bought Birdseye's patents and began marketing frozen fruits and vegetables.

In 1925, Clarence Birdseye, an American inventor, quick-froze fish on a refrigerated moving belt and started a new industry.

Despite uneven product quality, the use of frozen foods grew slowly but steadily during the 1930's. After World War II ended in 1945, and refrigerators and home freezers came back on the market, consumption increased more quickly. In 1948, U.S. production of frozen foods passed the billion-pound mark. But the new industry had serious problems. Consumers of frozen foods complained of changes in color and texture and loss of flavor. The industry also worried because frozen foods sometimes lost important nutrients and suffered occasional bacterial contamination during processing and storage. In the late 1940's, the industry began working with the Western lab to find answers to its problems.

What followed at WRRC was known as the Time-Temperature Tolerance (TTT) Project. Its aim, simply stated, was to improve the quality of frozen food. The project began with tests of 50,000 samples of frozen fruit and orange juice, but its scope was soon expanded to include vegetables, poultry, prepared foods, and bakery items. Building their own freezing facilities inside their lab, Western lab scientists experimented with every step in food freezing, from selection of the variety grown to harvesting, handling between field and plant, blanching and freezing, packaging and storage, and transport of the products to the market. What they learned during the next 8 years helped immeasurably to ensure the survival and growth of the U.S. frozen food industry.

Post-World War II research at the Western lab, known as the Time-Temperature Tolerance Project, helped solve one problem after another for the fledgling frozen food industry. The result today in the typical market is an amazing variety of convenience foods with acceptable flavor and texture.

A key discovery was that blanching, or scalding, is the single most critical operation in freezing vegetables commercially. Without adequate blanching to inactivate naturally occurring enzymes, storage life of frozen foods was limited to 3 months or less. Too much blanching, on the other hand, altered the color or flavor of vegetables or damaged texture. WRRC scientists developed a simple but sensitive biochemical test to detect enzyme activity after blanching. It was soon adopted by industry.

Also discovered was the cause of off-flavors and loss of vitamin C and sugar in frozen peas, which often deteriorated rapidly after removal from their pods. Scientists found that so-called delay off-flavor occurred when bruised peas were held too long before processing. As a result of the research, plant managers took steps to reduce the transit time for peas between field and plant. Sometimes, on hot days, peas are cooled with ice water immediately after picking. Today, plant operators communicate with the field by car radios to coordinate harvesting and processing and to minimize processing delays.

Keeping storage temperatures of frozen food cold enough was also critical. All frozen foods, researchers learned, have one characteristic in common: a limited tolerance to temperature fluctuations. It is essential to keep these products at 0° F or below. Frozen peaches, for example, will not turn brown for a year if they are packaged tightly and kept at 0° F. At 10° F, they will begin to turn brown after 45 days; at 28° F, in only a day. Frozen strawberries, if stored at 0° F, will retain all of their vitamin C. At storage temperatures warmer than that, they start losing it. Near the freezing point, at 30° F, scientists found that only a fraction of the vitamin remains.

Raspberries posed a special problem. In the Pacific Northwest in the 1950's, 10 percent of the raspberry crop had to be destroyed because of contamination by thrips, which are very small and destructive winged insects. The industry risked having whole shipments of frozen berries condemned. The simple answer to the problem, said WRRC researchers, is to wash out the raspberry thrips with detergents before freezing. The procedure reduced loss due to thrips to about 2 percent and kept the raspberry freezers in business.

Curdling of gravies and sauces in precooked frozen meats and vegetables was an annoying problem that threatened the growth of such convenience foods as TV dinners. Many household cooks had become discouraged with such preparations because so much stirring was required to smooth the gravy that the solid foods became mushy and unappetizing. The Western lab tried a technique used in preparing Oriental ceremonial foods—a flour made from waxy, or glutinous, rice instead of wheat flour to thicken gravies. Sure enough, they stayed smooth after freezing.

USDA scientists solved one frozen food problem after another, keeping the fledgling industry alive.

Later, waxy-rice flours were used to thicken frozen puddings, replacing the traditional cornstarch.

In time, WRRC scientists developed nine principles for freezing vegetables, still subscribed to by industry today. (1) The product must be freezable: peas freeze; cucumbers do not. (2) The variety must be suitable: garden peas, for example, freeze better than peas grown specifically for canning. (3) The raw product must be first class: freezing preserves defects as well as superior quality. (4) Handling between field and plant must be as prompt as possible. (5) Natural enzymes must be inactivated by blanching. (6) Freezing must be fast enough to ensure quality, yet economical enough to be competitive. (7) The plant must be kept sanitary and the line clean to prevent contamination by molds, yeasts, and bacteria. (8) Packaging must ensure that no moisture is lost during a year's storage. (9) Storage temperatures must be uniform and never, never exceed 0° F. The importance of this final item led to an industrywide Mark of Zero campaign to educate processors, shippers, marketers, and consumers.

Discoveries in connection with the TTT Project resulted in publication of some 100 scientific papers. Today, more than 30 years later, the Western lab still receives inquiries about freezing and storage techniques.

Several years after TTT was completed, engineers at the Western lab developed an experimental blanching method that retained 90 percent of the nutrients in frozen vegetables. Loss of nutrients posed a dual problem for the industry: The product was not only less nutritious but the organic materials left behind in the blanching water were a serious water pollutant. The new method was called individual quick blanching (IQB, for short). It ensures that each vegetable piece is uniformly heated to kill enzymes. The pieces are spread in a single layer on a moving belt that conveys them quickly through a steam chamber. They are held in the steam only long enough for the heat to partially penetrate each piece. Then the vegetables are piled up on a slow-moving belt that conveys them through an insulated chamber, where the heat already applied is redistributed and penetrates to the interior of each piece. Exposure time of each piece to halt enzyme activity is only one-fourth to one-half that required in conventional blanching. Quick-blanched frozen vegetables have a firmer texture and taste more like the fresh product.

Another WRRC lab innovation was dehydrofreezing. In this process, fruits and vegetables are partially dehydrated before freezing, cutting their weight in half. While the process has proved effective with a variety of products, its chief commercial use today is in freezing pieces of potatoes and apples for institutional use. Many researchers are willing to bet that the use of dehydrofreezing will soon be expanded.

Not every fruit and vegetable responds to conventional freezing—strawberries and green beans, for example. After thawing, juices leak from strawberry cells and green beans lose texture. WRRC researchers in the 1960's found that rapid freezing of berries and beans with liquid nitrogen resulted in much more satisfactory products. They also found that consumers were willing to pay a few cents more to take advantage of the improvements.

Loaves of frozen dough for bread also posed difficulties. While sales were brisk when these were first marketed, consumers were disappointed that the bread lacked the aroma, flavor, and texture they had expected. WRRC microbiologists found that freezing diminishes yeast activity, particularly when the bread has been stored for more than 2 months. In 1970, the product was improved in several ways, all aimed at increasing yeast activity. The result was a product that proved popular—and has stayed popular.

In 1978, a chemical engineer at the Western lab found that vegetables frozen in a liquid freezant require 25 percent less energy to process them than vegetables frozen in conventional air-blast freezers. Freezing times were reduced from 25 minutes to as little as 2. The freezant used in tests consisted of 15 percent table salt, 15 percent alcohol, and 70 percent water at a temperature of -6.7° F. Taste panelists said they liked mixed vegetables frozen in this manner as well as those frozen conventionally.

Surplus Oranges

Some 50 years ago, Florida oranges were a surplus crop. The only orange juice available was either squeezed from fresh oranges (a lot of trouble at 7 a.m.), mixed from a relatively flavorless concentrate (which remained unsold on grocery shelves), or poured from a can (which had a flavor all its own).

In 1946, Louis G. MacDowell, director of research for the Florida Citrus Commission, suggested that adding a little single-strength fresh juice, or "cut-back," to slightly over-concentrated orange juice might restore the flavor and aroma lost during vacuum evaporation. He and two colleagues took the idea to a field station of the Southern lab at Winter Haven, Florida, where USDA researchers had the equipment and expertise to help MacDowell develop his idea. They found that it not only worked but that the vastly improved concentrate could be easily frozen. USDA, as had been agreed in advance, took out a patent on the process. And so the frozen concentrated orange juice industry was born—an industry today worth $400 million a year in sales.

Juice

In 1940, children didn't run into the kitchen demanding a glass of juice. Chocolate milk, maybe, or soda pop, or even a glass of water, but not fruit juice. The beverage choices in 1941 were strictly limited. "Convenience" juices were canned or bottled, and their flavor typically bore only a superficial resemblance to the fresh article. Today, of course, a variety of juices with fresh fruit flavor pack the shelves and freezer bins in supermarkets.

While the postwar invention in Florida of frozen concentrated orange juice has been the celebrated commercial success in the juice line, research to create fruit essences began in the Eastern lab as early as 1943. First developed for apple juice, the process eventually proved capable of capturing most of the flavor of noncitrus juices.

It worked like this: Freshly pressed apple juice passed through an evaporator that vaporized the volatile flavors so quickly that little or no flavor change took place. The vapor containing the apple flavor, which amounted to from 10 to 20 percent of the juice, was then concentrated to about 1 percent of its original volume. This fruit essence could then be added back to the rest of the juice, which meanwhile had been transformed into syrup or concentrate, or used separately as a flavoring agent.

During the next few years, more than a score of firms applied the ERRC research, supplying fruit essences for jellies and preserves, candies, pancake syrups, flavoring extract, dairy drinks, and ice cream. A pint of fruit essence could flavor 100 pounds of preserves. This concentration of flavor and aroma made it possible to transport the essences cheaply over long distances and provided growers with a year-round market for many seasonal fruits.

Subsequent application of the research by ERRC scientists led to concentrated frozen apple juice and grape juice. Both products were developed at the Eastern lab; both returned the flavor essences to the juice after it was concentrated. An apple essence

In 1943, Clara Day of the Eastern lab pours a sample of concentrated apple syrup, one result of early research to capture full-flavor juice concentrates. The work led to development of frozen concentrated apple and grape juice.

Food technologist Kent C. Ng of WRRC prepares to test a new clear apricot juice. It is made by treating pulpy apricot concentrate with enzymes and then passing the mixture through ceramic filters.

made from peels and cores was also added to canned applesauce to fortify its flavor.

A way was also found to preserve apple cider, which normally has a short shelf life because it ferments so quickly into "hard" cider. Potassium sorbate was added to control yeast and mold formation, and refrigeration at 50°F was recommended to control bacterial growth. Ultraviolet light treatment was also used to prevent spoilage. Taken together, the practices extended the life of cider from a few days to several weeks. Cider makers using the preservative reported sharply increased sales.

Meanwhile, other regional labs were pursuing their own juice research. In the West, scientists located the cause of occasional gelling in orange juice concentrate. New processing equipment was squeezing more pectin and pectin enzymes from the orange peel into the juice. All too often, the enzymes would cause the juice to gel, and once gelled, the concentrate couldn't be reconstituted. A WRRC team found a way to inactivate the enzymes with steam injection heating and kept the industry from having to junk its new equipment.

Other juice innovations at the Western lab include:

- Methods for controlling heat-resistant molds in processed grape, pineapple, and other juices.
- A flash-heating system capable of sterilizing, concentrating, and cooling fluid foods in 1 second.
- A continuous method for making jelly with fruit juice concentrates that turns out a better product at less cost.
- Puff-dried citrus juice that can be readily reconstituted with water. Stable and lightweight, it's a boon to the military, campers, and backpackers.
- A sparkling clear frozen strawberry-juice concentrate for jellies and sherbet that uses berries too small or misshapen to make the grade in the fresh berry market.
- Prune juice produced by a continuous 30-minute process that uses an enzyme to break down pectin. A research bonus, the juice lacks the caramelized taste of old-style prune juice.
- A way to control the viscosity, or consistency, of tomato juice and other liquid tomato products by adjusting the acidity when tomatoes are crushed.
- An automated system for extracting juice from apples.
- The discovery that small wineries can freeze crushed grapes at harvest and hold them until their limited fermentation facilities become available.
- And very recently, a technique for making clear apricot juice using enzymes and ceramic filters.

At the Southern lab, whose scientists helped create frozen orange juice, researchers later developed superconcentrates of unsweetened lime juice. They also worked with the Georgia Agricultural Experiment Station to develop new peach products, including a clear peach-juice concentrate.

Flavors and Aromas

The taste and aroma of food is complex and often elusive. More than 40 years ago, a chemist in the Eastern lab, after many months of work, was able to identify 26 different flavor and aroma compounds in apple essence. All the chemicals added up to only 50 parts per million of the original apple juice. The analysis was a remarkable achievement, carried out as it was without the sophisticated analytical equipment available to researchers today.

In other fruits and vegetables, however, there are even more complex combinations of chemicals affecting taste and smell. An orange tastes like an orange, for example, mostly because of the aroma of the oil in the peel—a mind-boggling combination of more than 200 chemicals.

Much of the research on flavors and aromas has been carried out at the Western lab. In 1961, a chemist there demonstrated that flavor components in fruits can be incorporated into an

At WRRC, Chemist Gary Takeoka prepares a chromatographic column for tests capable of detecting flavor adulterants.

amorphous sugar mixture. These locked-in flavors were stable at room temperature and could be used to fortify flavors of candies, cookies, and cakes. This technique for capturing flavors/aromas has been used extensively by the food industry.

Meanwhile, other Western scientists began to study odor thresholds by taking each component of an aroma in turn and observing the point at which a particular concentration could first be detected by the human nose. This systematic approach enabled the chemists to determine which components in a complex mixture contribute most significantly to a characteristic aroma.

Some of the more important discoveries about flavors/ aromas at the WRRC include:

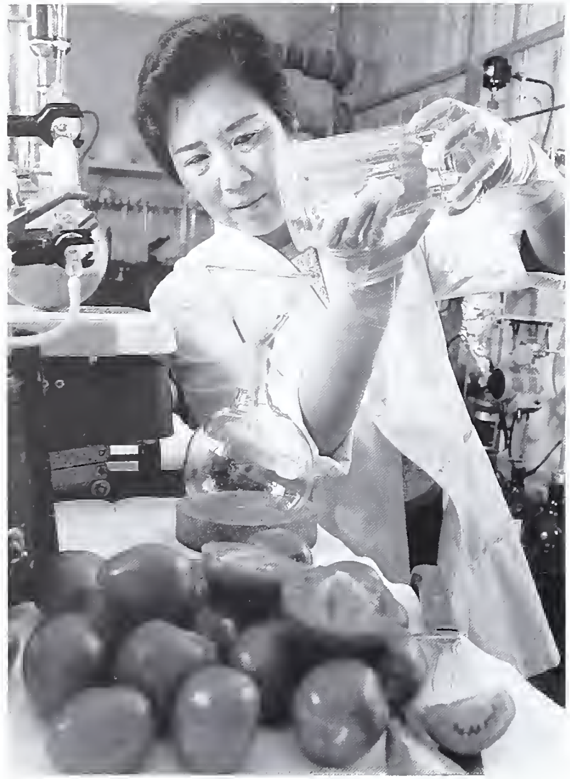
- Isolation and characterization of two of the most important flavoring constituents in an orange: alpha- and beta-sinensal. The chemicals were later synthesized, and the work led to a much better understanding of orange flavor.

- Identification and eventual synthesis of the major compound responsible for the aroma of the bell pepper. The chemical is used by processors today to restore the flavor of dehydrated peppers.

- Discovery of a hitherto unknown compound that gives one kind of aromatic rice its popcorn-like aroma. Aromatic rice is favored in most of the rice-eating countries of the world.

- Isolation of the flavor and aroma components that make a tomato picked fresh from the vine taste better than one purchased in the supermarket.

In part, these findings were made possible by an instrument indispensable to scientists today—the gas chromatograph (see chapter on "The Tools of Research," p. 35). Western lab researchers were the first to combine a capillary gas chromatograph with a fast-scan mass spectrometer to probe aromas. The method revolutionized the identification of constituents available only in minute quantities. Another useful technique, developed at WRRC in the 1970's, uses liquid carbon dioxide to extract aromas. Separation of aroma constituents is complete, and since the gas is nontoxic and flavorless, there is no damage to the chemicals extracted. Researchers also use computers to rank the most important natural aroma chemicals affecting the flavor of foods.



Physical science technician Louisa Ling of the Western lab prepares to test tomatoes to determine their flavor and aroma constituents at differing lengths of time after picking, storing, and cutting.

Important work on flavor has also been carried out in New Orleans. Southern researchers identified the flavoring components of celery as early as 1962. Researchers also used both the gas chromatograph and human taste panels to access the flavor potentials of new peanut varieties. Recently, they developed robotlike food tasters to trap and test flavor volatiles on the production line. The robots enable processors to reduce waste by identifying and replacing substandard ingredients during processing instead of waiting to test the end product.

At the Northern lab, researchers pioneered a technique known as dynamic headspace gas chromatography to learn more about compounds that sometimes give off-flavors to soybean oil. As in the South, human sniffers supplement instruments in monitoring vegetable oils in Peoria. "We put a nose in the computer loop," explains one scientist.

The human nose also gets a lot of respect at the Western lab. The flavor of high-quality fresh pineapple is largely the work of nine aroma compounds. One of these natural chemicals is so potent—or noses so sensitive—that panelists could detect its aroma at concentrations of only 6 parts per trillion. That is equivalent to six grains of sugar in an Olympic-size swimming pool. And an aromatic chemical in tomato paste could be detected by panelists at one part per 100 billion—the equivalent of a pinch of salt in 1,000 tons of potato chips. That last study, by the way, identified which of the 44 aroma chemicals in high quality tomato paste give the product its fresh tomato aroma. As in most such studies, the researchers have a practical objective. They hope that tomato paste processors, for example, will use their findings to check flavor quality—and possibly enhance flavor—by modifying procedures in their processing plants.

Aroma and flavor findings also help food processors to detect synthetic food flavors that are priced and sold as all-natural products. A WRRC research chemist, working with a California manufacturer, has come up with a new detection technique that easily separates key flavor compounds of certain fruits into two distinctive forms—one natural and one a tip-off to synthetic flavorings.

"Consumers expect to get what they pay for when they buy natural flavorings," says the researcher. "But it's easy to get fooled. One major jelly manufacturer, for example, asked us to use our new technique to check out an imported apple essence that somebody was trying to sell him. We found that one of the main flavor compounds in the essence was a blend of two forms of the aroma chemical. One was a mirror image of the other. That tipped us off that the essence was a blend of natural and artificial ingredients."

The scientist adds that there may be nothing wrong with a synthetic flavor. "It might taste just as good," he said. "But you shouldn't have to pay the natural-flavor price."

Processing Fruits and Vegetables

There are several reasons for processing fruits and vegetables. One is to arrest decay. The moment produce is harvested, it starts to deteriorate—from the action of its own enzymes, from the oxygen in the air, and from outside microorganisms. Another reason for processing is to make a product more convenient for people to use by peeling it for them, chopping it, squeezing it, seasoning it, and cooking it. Yet another reason is to transform a fruit or vegetable into an entirely different product, like plums into prunes, grapes into raisins, tomatoes into catsup, or cabbage into sauerkraut.

Consumers today buy many more processed foods than they did in 1940, when the regional laboratories began. The increase is due in part to the improvement in frozen foods, new food products, and invention of the microwave. But it also reflects the increased willingness of Americans, including a much larger proportion of women who work outside the home, to pay a higher price for faster, more convenient meal preparation, provided, of course, that the products meet their criteria for flavor and texture.

Processing makes a product more convenient for people to use by peeling for them, chopping it, squeezing it, seasoning it, and cooking it.

Food Process Engineering

Fifty years ago, when Americans bought much more of their produce fresh, the machinery of food processing in the typical kitchen included an orange squeezer, a grater, a potato masher, and the ubiquitous paring knife. But processing tons of food in a plant requires far more complex and ingenious machinery than that. Many of the most important machines and processes used by food processors have been invented in the regional laboratories.

Building on its own considerable experience in improving dehydrated foods for the armed forces during World War II, the Western laboratory continued after the war to pioneer additional improvements in drying processes and equipment. A belt-trough dryer, an entirely new type of dehydrator, was developed when existing dehydrators proved unable to dry fruits and vegetables uniformly enough to satisfy the requirements of new preservation techniques like dehydrofreezing. In the new WRRC dryer, pieces of the product were tumbled about in the trough of a moving belt. Simultaneously, a flow of air through the bed created a fluidizing action that dried the product quickly and without reducing quality. The dryer, developed at relatively little cost, was soon adopted by several processors.

Dry peeling of fruits and vegetables was another WRRC innovation, developed in response to more stringent restrictions on disposal of organic materials in plant waste water. The dry-peeled method, first applied to potatoes, reduced organic waste loads by as much as 80 percent. It was soon applied to other crops, including peaches and tomatoes. Besides reducing wastes, dry peeling also allowed recovery of tomato peel and pulp in such a clean, concentrated form that it could be incorporated in tomato concentrates and used as food.

Designing new equipment and techniques to process whole kernel sweet corn, WRRC chemical engineer George Robertson determines exactly how much force is necessary to remove an intact kernel of a particular variety of corn from the cob.

In improved system for processing sweet corn, split ears are rotated while being pushed against revolving drum. Rubbing action removes the kernels intact. The Western lab process reduces organic wastes by up to 80 percent.

Several years later, WRRC developed a low-water, nonpolluting method for cleaning fruits and vegetables with a gentle mechanical wiping action. As an unexpected bonus, the action removed any attached stems while cleaning tomatoes, solving the problem of an occasional stem turning up in a tomato product.

The Western lab's search during the 1950's for better ways to make tomato juice powder led to development of foam-mat drying, a method eventually used by citrus processors as well. An emulsifier is added to the tomato juice and the product is whipped into a foam. It then flows like whipped cream onto conveyors, where jets of air are directed up through the tomato foam, forming little craters that help the product to dry quickly. With improvements in the dryer, the foam could eventually be dried in as little as 12 minutes. The product is then crushed into powder for later reconstitution with water.

Other food processing inventions created in the California laboratory include:

- Drum-dried fruit flakes, currently in use to make instant applesauce.
- A helical sterilizer, which cooks delicate particulate foods like diced tomatoes without damaging them.
- A high-solids vacuum evaporator, known as the WURLING evaporator. It produces tomato paste with solids contents of from 40-45 percent, compared to 30-32 percent with conventional evaporators. The evaporator is used by canners in the United States and Italy.
- A comprehensive system of reverse osmosis as a low energy alternative to evaporation. The product suffers no heat

damage or loss of flavor and aroma. Processors are using the system today to produce tomato concentrates; the dairy industry uses a similar process to recover milk solids from whey.

At Wyndmoor, ERRC took a different approach to drying fruits and vegetables. Researchers there had observed that many dried foods rehydrated slowly and incompletely in boiling water. Even then, they sometimes contained areas that were tough, dry, and unappetizing. To surmount this shortcoming, ERRC modified the dehydration process, introducing a step it called explosion puffing. A partially dried apple piece, for example, is subjected briefly to high temperature and pressure, then released into the atmosphere, where it explodes, or expands instantly. The result is a lightweight, porous piece of apple. It can undergo further drying more quickly than an unexploded apple piece and reconstitutes in water quickly, fully, and evenly. Scientists found that this fast, gentle treatment is competitive with commercial air drying. Explosion puffing is now used in the United States to dry apples, blueberries, and carrots, and in foreign countries for potatoes and other vegetables. Modifications of the process are also used in the spice industry.

Foam spray drying, another ERRC development, was a response to industry's need for an economical way to dry high sugar/high acid products like cottage cheese whey. Moisture is difficult to remove from such products. In the process, air under pressure is introduced into the feed line between a pump and spray nozzle. The forced air turns the product being dried into a foam, which is then sprayed over a large surface area. The foamed droplets are easily dried and reconstitute well. A modification of foam spray drying is used by industry today to make powdered fruit juice and chocolate beverage powder.

In 1961, the Western lab treated high-moisture prunes and other dried fruits with potassium sorbate to prevent mold growth. High-moisture dried fruits are tenderer and more succulent than conventionally dried fruits. With sorbate, they can be packed in plastic bags or cartons without fear of spoilage. Industry adopted the practice in 1963.

New and faster methods of drying raisins, America's largest dried fruit crop, were also developed by WRRC chemists and engineers. Grapes are not usually ready for harvest in California until September, when there is often a chance that an early rain might damage them during their 2 or 3 weeks of exposure while drying in the sun. In 1978, for example, a disastrous rain cut raisin production from an expected 270,000 tons to about 100,000 tons.

To reduce the risk of rain damage, WRRC, in cooperation with California State University, Fresno, developed a water emulsion

Explosion-puffed dehydrated blueberries were an ERRC innovation. The technique can also be used to preserve apples, carrots, and other products.


Among the many uses today for explosion-puffed produce are dry mixes for blueberry muffins.

ERRC scientists first developed a way of measuring "browning." Then they found various chemicals, including derivatives of vitamin C, that could prevent it, and with no detectable change in taste.

Lowering Fruit Moisture with Osmosis

When you sprinkle sugar on fresh strawberries and the juice oozes out to make a syrup, you are witnessing osmosis. It is defined as the tendency of a solvent to pass through a semipermeable membrane, like the wall of a strawberry cell, into a solution of higher concentration. The solvent (in this case, the strawberry juice) will continue to pass into the syrup until concentrations are equal on both sides of the membrane.

WRRC researchers have found that osmotic concentration is a practical, low-energy way to remove half the moisture from apples, peaches, and apricots without hurting the fruits' flavor, color, or texture. Traditional ways to reduce moisture in fruit pieces include hot-air drying, which requires large inputs of energy.

In the laboratory, cut-up fruits were immersed in a 70-percent sugar syrup. After 6 hours at about 160°F, enough internal moisture had migrated from the fruit to dilute the syrup to a 60-percent concentration. Researchers found that they could reconcentrate the diluted syrup back to a 70-percent concentration and reuse it five times without affecting fruit flavor or appearance.

spray containing a vegetable oil derivative that accelerates drying. Normally, the waxy outer layer of a grape acts like wax paper to keep the moisture in. The spray, by interacting with the waxy layer, allows internal moisture to escape faster so that grapes dry in about half the time. Two other approaches to drying raisins make use of inexpensive solar collectors—long tunnels of black polyethylene plastic that heat the air and speed drying. Both solar methods reduce drying time for raisins by about 40 percent.

In the South, cooperative research with the North Carolina Agricultural Experiment Station and with industry led to development of pasteurization for pickles, necessary to prevent growth of the wrong kind of microorganisms. The process proved adaptable to continuous and batch operations, and commercialization led to rapid expansion of fresh-pack pickle products. In addition, soft pickles were practically eliminated after scientists identified the enzymes responsible for softening during brining. As a result, the industry altered its processing.

Lightly Processed Fruits and Vegetables

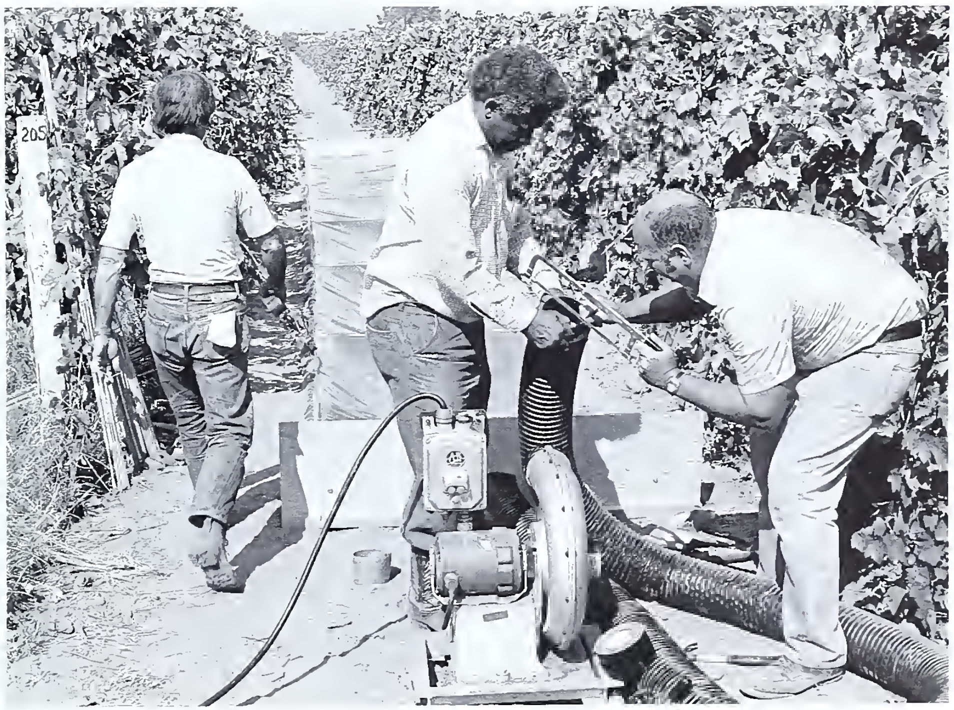
Consumer demand continues to increase for produce with freshlike appearance and flavor that is either ready to eat—or almost ready. The selections at restaurant or supermarket salad bars are but one example. For a time, normal discoloration of pre-peeled and pre-sliced raw fruits and vegetables was temporarily prevented by spraying them with sulfites. In 1987, however, the Food and Drug Administration banned the use of sulfites for controlling browning because some people—primarily asthmatics—are allergic to them. Several ARS research facilities, including the laboratories in Wyndmoor and Albany, began looking for substitutes for sulfites. They have already found several.

At ERRC, the focus was on browning, weight loss, and softening of apples, pears, and potatoes. Most browning of fresh fruits and vegetables is caused by food enzymes. A team of six scientists first developed a method for measuring enzymatic browning and then found various chemicals that could prevent it. Several related compounds are derivatives of vitamin C, or ascorbic acid. When used as a dip for fruits and vegetables, they gradually release vitamin C to keep dark pigments from forming. One such compound, tested on apples and potatoes, prevented discoloration for 48 hours. Researchers could detect no change at all in taste.

Another ERRC approach uses carbohydrate compounds called cyclodextrins to prevent natural components in juices from turning brown. Cyclodextrins are derived from cornstarch and can prevent browning in refrigerated juices. Further research is under way to control browning of juices by removing the natural enzymes responsible.

Scientists at the Western lab have pursued other avenues of research in improving lightly processed foods. They are exploring, for example, new and cleaner slicing techniques that use lasers or powerful jets of water called water knives. The idea is to control growth and spread of bacteria and other microorganisms that attack freshly cut produce. They have also discovered that an edible solution of zinc chloride delays browning of sliced apples, pears, and peaches for days or even weeks—if the fruit is bagged quickly and refrigerated after its zinc bath.

Other WRRC researchers have created edible coatings made from the casein in milk to protect the flavor, color, texture, and nutritional value of freshly cut fruits and vegetables. The nearly invisible, tasteless coating becomes in effect an artificial, edible peel. It walls out microorganisms that cause decay, traps moisture to keep the produce fresh, and lets it breathe on the shelf. In laboratory tests, small pieces of sliced and peeled apple dipped in the casein-based liquid stayed fresh for several days. Other safe-to-eat films could be made from proteins, as in soybeans, corn, or wheat.


Food technologist Rogernald Jackson holds while agricultural engineer Charles C. Huxsoll of the Western lab trims plastic tube for snug fit onto electric blower. Air will be circulated between polyethylene sheets, which will form a solar tunnel to speed drying of grapes for raisins.

A chemist at the Western lab has also found a way to keep pre-peeled and bagged carrot sticks from discoloration by a harmless but unattractive white film. One answer is to dip the carrots in a hot solution of citric acid, followed by a quick dunk in cold water to prevent heat damage. Carrots so treated are additive-free and will retain their original bright color for at least 3 weeks in cold storage.

Soft-rot, a major cause of postharvest losses in fresh fruits and vegetables, is caused by microbial enzymes. It can occur whether or not the produce is processed. ERRC researchers have been studying the genetic structure of bacteria producing the soft-rot enzymes and are investigating two approaches to their control. One is the use of naturally occurring molecules that act as bacterial antagonists. The other is the use of a chemical called EDTA, which is shorthand for ethylene diamine tetra-acetic acid. EDTA inhibits the action of the bacterial enzyme, and in laboratory tests, it protects potatoes and green peppers from soft-rot.

Selecting Varieties for Processing

Not every fruit or vegetable, no matter how delicious when fresh, will stand up well to processing. The New Orleans laboratory has for many years evaluated new breeding lines of fruits and vegetables for their processing properties. The evaluation, which is carried out in cooperation with Federal, State, and industry scientists, takes place before the variety is released. It has proved invaluable in discouraging farmers from planting varieties unsuitable for processing. Even those farmers who grow produce primarily for the fresh market prefer to plant dual-purpose varieties in case oversupply pushes fresh market prices down to profitless levels.

White Potatoes

Scientists at the Eastern lab were excited enough about development in 1954 of a method for making dehydrated potato flakes to hold a rare press conference to report the research, one of their most significant accomplishments in food process engineering. They explained how potatoes are pre-cooked, cooled, cooked under carefully controlled conditions, mashed, and spread onto a heated drum. They pointed out that starch granules are not broken in the process—an important key to the quality of the product—and that the dried potatoes come off the drum in a thin sheet that is broken into flakes.

To find out if the product could be produced commercially, a carload of Maine potatoes had been processed into flakes at a pilot plant constructed inside the ERRC. Subsequent market tests of the finished product indicated that consumers would buy and use potato flakes. The first commercial production began in 1957, just 3 years after the press announcement.

Development of the flakes helped reverse a downward trend in per capita consumption of potatoes in the United States. Before the flakes came along, powdered dehydrated potatoes had been marketed but found little favor with consumers. The ERRC product, however, was different. Prepared according to directions, the flavors and consistency, according to taste panels, were excellent. Once on the market, many restaurants and institutions, as well as home cooks, soon stopped peeling potatoes in favor of the new product.

In 1960, six processors converted more than 4 million bushels of fall potatoes into flakes, an unusually quick application of a new process by industry. Today about 400 million pounds of potato flakes worth $400 million dollars are produced each year in the United States. Many undergo further processing into a variety of deep-fried products, including new types of potato chips.

By 1960, the Western lab followed the ERRC's research with development of a satisfactory potato granule. Its success depended in part on the use of a fluidized bed dryer, adapted by WRRC engineers to process the granules. The dryer consists of a long box or trough with a porous ceramic bottom. Warm air, blown up through the bed, suspends the granules and dries them quickly and gently. Potato granule manufacturers soon began using variations of the bed dryer to produce their product, considered by some consumers as an improvement in flavor over potato flakes.

Other products followed: explosion-puffed potatoes in ERRC; a way to make crisper french fries using infrared lamps at the WRRC. The high heat from the lamps forms a thin shell on the potatoes so that they get crisp while absorbing less fat.

One result of potato product research at Department of Agriculture labs and at other research facilities is that people eat more potatoes today than they did in the 1950's. Another result is that 60 to 65 percent of the potatoes purchased by the American consumer today are processed. Only 1 potato in 3 is peeled at home.

Sweetpotatoes

Sweetpotatoes grow in many shapes and sizes, some of them too large or misshapen for either the fresh or canning market. In 1960, SRRC researchers found a use for these odd-sized potatoes by developing a dehydrated sweetpotato flake. The process was similar to one developed earlier at Wyndmoor for white potatoes. Addition of hot water yields mashed sweetpotatoes. The product has been used for school lunches and for military use overseas, as well as for other institutional purposes.

Engineers in ERRC pilot plant process mashed potatoes into a continuous sheet that can be broken up into instant potato flakes.

Harvesting Cherries Mechanically

About three-fourths of America's red tart cherries—pie cherries—are grown in Michigan. In the 1950's, annual production in that State was about 190 million pounds, all harvested in a scant 3 weeks by an army of 45,000 migrants. But it was getting harder every year to recruit pickers (and to afford them), and there was pressure on Congress to reduce the supply of foreign migrants. (At the end of 1964, it finally happened.) What was needed, agreed ARS engineers at Michigan State University, was a machine that would shake the cherries off the tree. And in the early 1950's, despite catcalls from critics who warned that machine harvesting would damage cherries too much, they began to work seriously on the project.

A motor started and the tree shook violently, a storm of cherries falling into a net spread below. The crazy contraption worked!

Meanwhile, in Pennsylvania, ERRC chemists were taking a critical look at the impact of hand-harvesting on red tart cherries. They were more concerned with improving product quality than with economics or labor. The number one reason for downgrading cherries in canneries, they found, was bruising, and they proved that human beings caused most of the bruising as they picked the cherries and dropped them into pails. Perhaps cherries would bruise less, they speculated, if they made a softer landing in something like a minnow net. Before long, the ARS engineers in Michigan and the ARS chemists at Wyndmoor were working together. The result of their collaboration was the mechanical cherry harvester, first demonstrated to growers in a Michigan orchard in 1959. They watched skeptically as a tractor pulled an odd-looking machine into position underneath a cherry-laden tree and a clamp at the end of a mechanical arm was secured to a branch. A motor started and the tree shook violently, a storm of cherries falling into a net spread below. The crazy contraption worked!

Like most major innovations, creation of a prototype machine was but the first step down a long rocky road. ARS engineers improved their invention, got the bugs out. Growers, dubious at first, grew enthusiastic as they found out that one mechanical shaker with a crew of 5 could harvest as many cherries in a day as 100 handpickers.

But canners remained unsold. The team of ERRC chemists kept working with them and with manufacturers of processing equipment to help solve their problems. In time, aided by the invention of an electric cherry sorter in 1963 and a device to remove stems from cherries without bruising them, processors began to welcome cherries harvested by machine. In 1966, for instance, only about 22 percent of Michigan's cherry crop was machine-harvested; in 1967, it was 50 percent. Today most of the crop is harvested with shakers, and production of red tart cherries, a crop that once seemed doomed, is higher than ever.

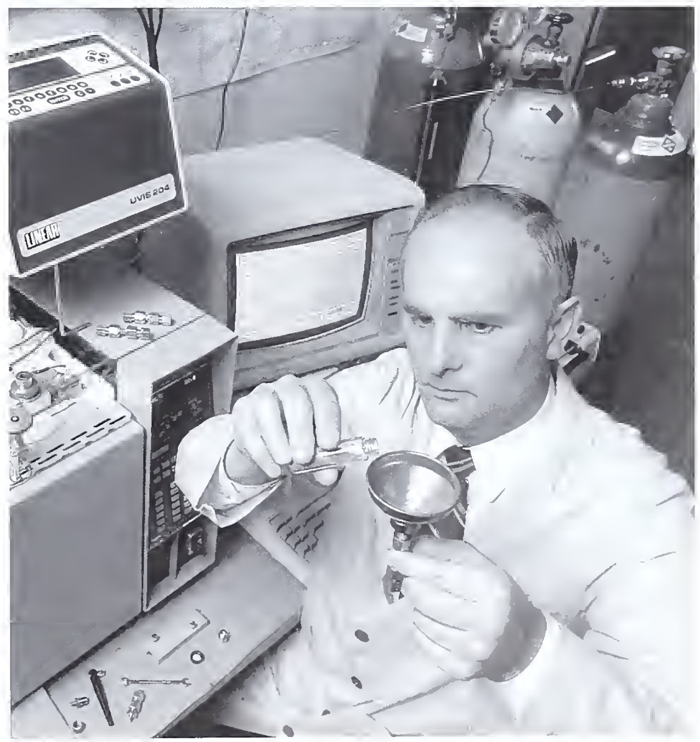
Supercritical Extraction

In the early 1980's, while working on a project involving high-pressure reactions, NRRC scientists at Peoria began to experiment with an intriguing property of carbon dioxide, reported earlier by German researchers. When subjected to a pressure of at least 1,100 pounds per square inch and held at a temperature above 31°C, carbon dioxide remains a gas but takes on the density and some of the properties of a liquid.

In this intermediate pressurized state, called supercritical by chemists, the carbon dioxide can flow through materials like flaked soybeans, corn germ, coffee, or spices, and dissolve the oils in those materials. In some cases, these oils contain the flavor essences. When the pressure is reduced, the carbon dioxide reverts to a gaseous state, leaving the liquid oil behind.

The first thought of NRRC chemists was that the process, which is completely safe and nonpolluting, could be substituted for current methods of extracting soybean oil with hexane, a petroleum derivative and an explosive solvent. Further research proved that the new process is indeed effective in extracting vegetable oils. But costs of plant conversions and problems in processing large quantities of oilseeds has so far discouraged adoption of supercritical extraction in the vegetable oil industry. There appear to be many immediate and practical uses for the process, however, and new applications are being found each year. Supercritical carbon dioxide can remove the caffeine from coffee, extract hops for flavoring beer, and refine many spices. At the Southern laboratory, it has been used to extract oil from dark-roasted peanuts with many more flavor and aroma components than oil extracted by pressing. An Italian scientist visiting the Peoria lab used the process to extract oil from the seeds of the evening primrose. The product was free of the chemical residue associated with hexane extraction. (Proponents of primrose oil, which sells for as much as $22 an ounce, insist that it is a remedy for a host of ailments, but the claims have yet to be proven to the satisfaction of U.S. medical scientists.)

Among the most practical uses of the carbon dioxide process is to analyze meat samples for pesticides and to check soil samples for possible contaminants. In lab experiments, lard samples were contaminated with lindane, endrin, and other pesticides and then subjected to supercritical extraction. Analysis disclosed that nearly 100 percent of the pesticides were removed by the process. Subsequent experiments with ground-up sausage and hams also proved the value of the extraction method in testing meat products. In 1989, the process was used to analyze soils suspected of containing high levels of organic compounds, such as animal and processing wastes. The carbon dioxide penetrated the soil samples easily and picked up organic compounds missed by other solvents. The process could help identify potential sources of groundwater pollution.



Supercritical carbon dioxide can remove the caffeine from coffee, extract hops for flavoring beer, and refine many spices.

Waste Management

Processing agricultural commodities creates mountains of wastes. They include corncobs and feathers, peelings and pits, straw and hulls, and manure and slaughterhouse offal. Producers and processors of farm products must either find practical uses for these billions of tons of wastes or dispose of them in ways that do not pollute the soil, water, or air. All four regional research centers have contributed to solving the vexing problems of agricultural waste management, and they have occasionally found ways to reduce nonagricultural pollution as well.

Corncobs are an example of a nonpolluting waste product that just keeps piling up. Corn is America's biggest row crop, and every ear of corn has a cob. Many, many uses have been found for corncobs, including corncob pipes, but one of the most unusual was discovered during World War II. The Northern laboratory at Peoria, in cooperation with the U.S. Navy, developed a method for cleaning the Navy's airplane engines by air blasting them with ground corncobs.

Each engine had to be overhauled after 800 hours of flying time to remove carbon and oil deposits that built up in cylinders and on pistons. The Navy first tried scouring them with corn grits in sand-blasting machines, but NRRC and Navy maintenance people soon found that a mixture of 60 percent ground corncobs and 40 percent unground rice hulls lasted 10 times longer than corn grits. The soft cob particles cleaned the carbon, oil, and scale from the engines without damaging the metal parts, and they could be used repeatedly until they finally turned to powder. Fifty new plants were built during the war to grind corncobs for this purpose, and soft-grit blasting was soon adopted for a number of industrial uses.

Another wartime use of corncobs, as well as of oat and cottonseed hulls, was in making an amber-colored liquid called furfural. The chemical had a number of pre-war uses in industry, including refining lubricating and diesel engine oils and making resins and plastics, but the market was not expanding very fast. During World War II, however, with foreign supplies of natural rubber cut off, furfural was found to be one of the best chemicals for purifying butadiene, used in making synthetic rubber. NRRC researchers developed a practical way to make furfural from the carbohydrates in corncobs, transforming them into one of the raw materials used in a new government-built furfural plant at Memphis.

Typical corn production today yields about 35 billion tons of corncobs every year, most of which are plowed back into the soil. But thanks to research, a substantial number also find their way into industrial paper, hand soap, animal feeds and bedding, sweeping compounds, and plastic fillers. Ground corncobs are even used to clean carpets and furs.

The Northern laboratory . . . developed a method for cleaning the Navy's airplane engines by air blasting them with ground corncobs.

Feathers were another waste product that tended to pile up fast, particularly with postwar centralization of the poultry industry. Feathers were a liability for poultry processors, who had to pay to dispose of them. After looking at several alternatives, Western researchers decided that their most practical goal would be to convert the wet, dirty feathers into a usable, salable product.

The best answer, they found, was to pressure-cook the wet feathers in rotating dry cookers, commonly found in rendering plants. Heating decreased the tensile strength and elasticity of the feathers, allowing them to be ground into a meal for fertilizer. Further research upgraded the product to a protein feed supplement. Within a few years, about 80 percent of the feathers from poultry processing plants was being converted to a high-protein feed supplement. Instead of costing processors $5 a ton for disposal, feather meal was soon an asset, selling for $100 a ton.

One of the most troublesome problems of agricultural wastes was experienced by the dairy industry, and immediately after the war, research began at the Eastern lab to find some answers. Water used for sanitation and cooling in dairy plants had 3 to 4 times the polluting strength of raw sewage. More and more municipal sewage plants in the late 1940's either charged dairies a premium price for handling their wastes or refused to accept them at all. In rural areas, untreated milk plant wastes were often discharged into small streams, where they depleted the water's oxygen supply and caused serious pollution.

In 1948, a dairy industry committee asked the ERRC to find an inexpensive way to treat dairy wastes and wash water by aeration. After several years of research, researchers developed a laboratory-scale process based on their analysis of the biological-oxygen demand of dairy wastes. It was a simple, two-stage disposal system that used both aeration and bacteria to oxidize the organic wastes. Under a government contract, engineers at Pennsylvania State University translated the ERRC findings into the design of a full-scale dairy waste aeration unit. The pilot plant proved effective and economical. Dairies, some of them plagued by State and civil actions, soon built similar plants. Many discovered that as a result, they were able to handle several times as much milk. The continuous digestion process for treating dairy wastes is widely used today, not only by dairies but also by citrus, canning, pharmaceutical, paper, and other industries. (Whey, another vexing waste product of the dairy industry, is discussed in a separate chapter.)

Meanwhile, the Western center in California found a way to convert waste from pear canneries into molasses and dried pulp to feed cattle and sheep. The process, which also worked with cannery wastes from peaches, grapes, and tomatoes, was similar to one developed earlier in Florida to utilize citrus industry wastes. In other research, a Western lab chemist found a way to recover more lanolin from wool after washing, or scouring, it. The process not only produced more lanolin for industrial uses, but it resulted in much less stream pollution from wool grease.

One use for artificial gravel, made by combining cellulose xanthate with soil, is to surround perforated drainage tubes to prevent clogging of holes by fine soil particles. WRRC researchers Earl Hautala (left) and Emory Menefee developed xanthate from waste cellulose products.

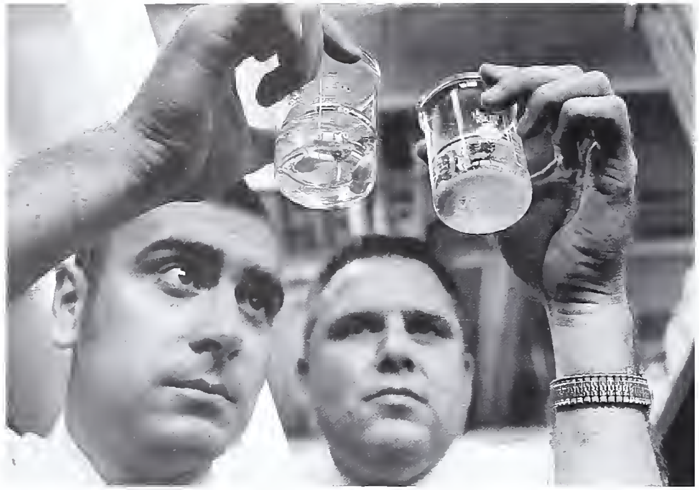
In the 1960's, the Western center set out to find better ways to peel fruits and vegetables for processing. Aims of the research were less waste and reduced stream pollution. The peeling method then in use by the industry began with softening the skins with steam or a lye solution, followed by high-pressure sprays of water to flush away the peels. Tough new State and Federal antipollution regulations, however, made it imperative for the processing industry to come up with new peeling methods that used less water and fed fewer pollutants into waterways.

A patented new method from WRRC scientists removed peels and skins without water. Instead, so-called dry scrubbers rubbed off the lye-softened peels. One type of apparatus consisted of spinning rubber-tipped rolls that abraded the peel from the product without damaging the underlying edible tissue. It worked well with potatoes and other root crops. Another WRRC invention fed the produce onto a bed of rotating rubber disks that wiped off the skins. It proved effective for soft fruits, such as cling peaches, apricots, and pears, and it was later modified to peel tomatoes.

A new compound from cornstarch was found to remove heavy metals from polluted water.

The new techniques, which won widespread recognition for the inventors, enabled processors to comply with antipollution rules. They also allowed recovery of much more of the peel and trim in the form of solids, which was then converted to cattle feed.

Within a few years, Western lab scientists developed yet another way to remove tomato peels. Tomatoes were first heated with steam to loosen the peels, then cooled quickly in a water bath. The quick heating and cooling sequence was repeated three times, after which the skins were removed mechanically. The water used in this process was recycled, and more of the edible pulp of the tomatoes was preserved for canning.



Peoria researchers Robert Wing (left) and Charles Swanson examine beakers containing starch xanthate and water contaminated with mercury. The mercury compounds have been precipitated, and the recovered mercury can be reused. Starch xanthate can also recover other heavy metals.

In several instances, the regional laboratories found ways to use surplus agricultural materials to fight pollution from mining and heavy industry. At the Northern lab, scientists found that a compound made from cornstarch (or any other starch; see p. 120) could be used to recover mercury and other heavy metals from polluted water. Insoluble starch xanthate (ISX), when added to mercury-laden waste water, attracts the heavy metal, combines with it, and carries it to the bottom of the tank, leaving a clear filtrate behind. The starch xanthate process also works well with lead, silver, chromium, cadmium, copper, lead, and nickel.

At the Southern lab, researchers learned that several compounds being tested as durable-press finishes had an affinity for metal salts. Cotton treated with these chemicals can be used as a trap for waterborne heavy chemicals. The special fabrics can be regenerated for repeated use. In tests, they proved capable of reducing the mercury content of contaminated water below the level permitted in drinking water.

Researchers at the Western lab tested a wide range of agricultural materials and byproducts for their ability to remove heavy metal salts and radioactive metals from water. Studied for their binding action were wool and feathers, bark, orange peels, rice straw, plum pit shells, peanut and rice hulls, and sugarcane bagasse. Redwood bark and other materials high in tannin proved effective in binding the metallic ions in polluted water. The metals could then be reclaimed for reuse.

Adding sewage sludge to barren coal mine wastes makes it possible to grow healing vegetation.

Another waste disposal challenge in the early 1970's confronted California's pickle and olive packers. They were releasing millions of gallons of pickling brine into waterways each season, and proposed legislation was about to limit the dumping of saline liquid waste. Engineers at the Western lab developed a practical method for reclaiming the salt from the brine. The heart of the process was a submerged combustion evaporator that reduced the salt and other products in the used brine solutions to a slurry. Organic contaminants were incinerated, remaining carbon was filtered out, and the salt was ready for reuse in the next cucumber and olive season. A pilot plant built at the California laboratory worked so well that a private manufacturer began making and marketing a brine disposal and salt recovery system based directly on the WRRC process.

Occasionally, the regional labs have found uses for wastes that help solve other environmental problems. One of the most serious is soil erosion from the action of wind and water. Erosion not only depletes the productivity of the soil, but eroded soil is the number one pollutant—in volume—of America's streams and rivers. In an effort to slow soil losses, Western lab researchers have developed an inexpensive soil amendment. Cellulose xanthate, made through a simple chemical treatment of wheat or rice straw, has the ability to bind soil particles together. When a small amount of a cellulose xanthate solution was sprayed on soil in a test pilot, it reduced soil erosion to less than one-half of 1 percent of that in untreated soil plots.

At the Northern center, researchers found that adding sewage sludge from municipal treatment plants to barren coal-mine

In Western lab, engineer Everett Durkee removes recycled salt left from olive processing after contaminants are incinerated. Salt can be reused during next olive season.

wastes makes it possible to grow healing vegetation where not even a weed would grow before. The surface-mine reclamation study was carried out by NRRC in cooperation with the Greater Peoria Sanitary District.

In other NRRC research, it was found that encapsulating the herbicide atrazine in cornstarch sharply reduced leaching of the chemical down through the soil, where it could reach groundwater and contaminate it. Studies of a cornfield where atrazine had been applied for 8 years showed that the cornstarch jackets cut leaching losses of the chemical from 35 percent to less than 1 percent.

In the mid-1980's, with oil spills on the increase, an NRRC chemist reported that crop residues might be used to remove small amounts of oil emulsified in water. Straw from small grains and cornstalks, cobs, and husks can be treated with inexpensive chemicals to balance their affinity for oil with their affinity for water. The patented treatment causes the residue fibers to swell and separate in water to provide maximum surface area for oil removal.

Meanwhile, researchers at the Southern lab discovered a way to liquefy waste solids from catfish processing plants for a variety of uses. The heads, skins, and viscera of catfish make up from 35 to 40 percent of the weight of a whole fish, and these wastes add up to several million pounds a year. SRRC scientists found that small amounts of formic acid act as an inexpensive catalyst to activate powerful enzymes in the gut of catfish. These proteolytic enzymes can turn the wastes to liquid in just a few hours. After the bones are filtered out, the liquid can be sold for use as a home or nursery fertilizer, as a high-protein feed supplement, or as a fish flavor for catfood.

The Scientists

Except in photo captions, there are very few names in this book. That is not because scientists prefer anonymity; far from it. Like most other men and women, they appreciate credit; they have no objection to seeing their names in print. But hundreds of scientists and technologists have been responsible for the many research projects described in ***Always Something New***, and space limitations will not permit identifying them, even when their specific contributions are known or remembered.

A scientific discovery or invention is rarely the work of only one man or woman. Even Edison had a shop filled with creative assistants. It is commonplace today for important research projects to be carried out by a team of men and women trained or experienced in several disciplines. In the Western laboratory, for instance, a research team that is using the tools of biotechnology to improve the quality of wheat proteins includes a chemist, a biochemist, a microbiologist, a geneticist, a physical chemist, and a biologist with special training in plant tissue culture. The particular expertise of each of these specialists is essential.

The image of the scientist presented in the black-and-white films of the 1940's, of an antisocial eccentric working in secret in a tower laboratory, probably never had any validity. It certainly doesn't today. Today's researcher, far from being a recluse, is a member of one or more professional societies; a chemist may belong, for example, to the broadly based American Chemical Society and the more specialized American Oil Chemists' Society. Typically, a scientist keeps up with change by reading the society's professional journals and attending local, State, and national society meetings. It is not unusual for an ARS researcher to serve as an officer of one of these societies or to receive its top honors or awards.

The image of the scientist presented in the black-and-white films of the 1940's, of an antisocial eccentric working in secret in a tower laboratory, probably never had any validity. It certainly doesn't today.

Regional lab scientists also attend (and often address) industry meetings related to their research. For example, Peoria cereal

Increasingly, complex research projects are carried out by teams of scientists trained in several disciplines. In the Peoria center, for example, the research group studying Fusarium *mycotoxins includes (clockwise from front) organic chemist Odette Shotwell, research associate Yangkyo Salch, chemist Susan McCormick, microbiologist Thomas Hohn, chemist Harold Gardner, biochemist Anne Desjardins, and geneticist Marian Beremand.*

chemists participate in corn utilization conferences held by the National Corn Growers Association. In addition, scientists in the course of their work develop close working relationships with industry researchers and university and State experiment station people. Increasingly, ARS researchers also work with industry people to iron out problems that may arise in transferring technology from the lab bench to the manufacturing process. No researcher works in an ivory tower.

What sets the scientist off from people in other lines of work is adherence to the scientific method. Scientists ask questions that have not yet been answered. They look for answers through systematic observation and orderly experimentation. While it is part of their method to speculate, they know the difference between a hypothesis, which has been described as an "educated guess," and a theory, which is a hypothesis that has undergone rigorous testing and investigation. Only rarely does one hear a scientist refer to a finding as a "fact".

"While some discoveries are unexpected, chance favors the prepared mind."

. . . Louis Pasteur

As much as any accountant, a researcher is scrupulous in keeping records; every experiment, every scrap of data, is carefully recorded and dated. When scientists believe they have proved their theories sufficiently or made original discoveries, they must publish their methodology and results where their colleagues can read them, and, if they so wish, build on them, criticize them, or even refute them. Science is not a profession for the thin-skinned or for prima donnas.

The process of submitting a scientist's work to the scrutiny of other scientists is called peer review. In the Agricultural Research Service, peer review is used in several ways: To examine the quality of specific research projects, to assess the agency's national research programs, and to evaluate its research personnel for possible advancement. There are few areas of human endeavor in which a person's work is subjected to such intense and frequent review by peers as in the sciences.

Scientists do not always remain in the area of study or specialization in which they began their careers. Many change fields several times in a lifetime, pursuing exciting new interests. And they frequently make important contributions in the new area. That is understandable; the body of scientific knowledge is expanding so rapidly today that researchers must continuously relearn their disciplines; scientific information doubles every few years. A scientist may have little more difficulty in becoming proficient in a related field than in keeping up to date in an old one and may bring fresh insights to the new disciplines.

"I would not want nonscientists to suppose," says a regional lab researcher, "that we are flawless automatons, invariably moving toward solutions of problems in an orderly way, from point A to point B. As Charles Kettering, the inventor of the self-starter for automobiles, pointed out, scientists and inventors typically fail more often than they succeed. That is the price of exploring the unknown. And sometimes, we make important discoveries by accident—or find that an invention or process is good for something other than what we invented it for."

He mentioned several unexpected spin-offs from research at the Western lab. In one instance, an enzyme isolated from papaya to tenderize meat was found to help treat herniated spinal disks. In another, shrinkproofing wool was found to make it more receptive to dye and easier to clean. He had a dozen other examples, all purporting to demonstrate that scientists are, after all, human beings who occasionally make mistakes or have lucky breaks. What he didn't say, however, was that it takes an alert scientist to spot the significance of research "accidents" and to make the most of them. As Louis Pasteur said, "Chance favors the prepared mind."

The Tools of Research

A former director of the Peoria laboratory explained in one sentence his formula for obtaining satisfactory research results. "Employ the most competent scientists you can find," he said, "supply them with the best scientific instruments and equipment, explain your research goals, and then back off and let them work."

The "best" in laboratory tools when the regional labs began was a far cry from the instruments of the 1990's. The equipment in the regional laboratories in the 1940's was made mostly of glass and wood and brass. Only the glassware would appear familiar to a young scientist today: Petri dishes and flasks and beakers and condensers. The old-fashioned microscope with its brass fittings and the wooden box of apparatus for blowing glass would look like museum pieces. Computers? A slide rule lay on every bench.

Today the typical laboratory in any of the four centers is filled with what researchers call black boxes. Most are electronic devices, and their color is more likely to be metallic silver than black. They bristle with switches and dials and tubes. It's unlikely that the 1940 chemist would have had any idea what to do with them, but they are indispensable to the 1990 researcher. Particularly as analytical tools, they make it possible to ask many questions—and to answer them—that couldn't even have been considered 50 years ago.

While few of the instruments were invented in the regional labs, the scientists there have used them in many new ways and develop important new techniques of analysis. An example is chromatography, a technique that began to be used at the centers in the late 1940's. A chromatograph separates mixtures of substances and enables the chemist to discover what compounds are in them and in what amounts. It replaced painfully slow, one-compound-at-a-time analysis using qualitative and quantitative methods. One form of the technique, gas-liquid chromatography, enables a chemist to identify the chemical compounds present in a gas or in a substance that has been converted to gas by heating.

Scientists at the Western laboratory in 1954 became the first to use gas-liquid chromatography for the study of volatile organic substances in foods. To accomplish this, they made several improvements in the technique, including increasing its resolution. This in turn led to coupling the gas chromatograph to another instrument called a fast-scan mass spectrometer. This is an electronic tool for analyzing gases that provides positive identification of mere traces of substances. The contributions of these WRRC researchers to the art of identifying the most minute constituents of complex mixtures have since been recognized by scientists all over the world.

"Employ the most competent scientists you can find, supply them with the best scientific instruments and equipment, explain your research goals, and then back off and let them work."

. . . a former director of the Peoria Laboratory

One basic analytical technique, known as thin-layer chromatography, was invented at the ARS laboratory in Pasadena, then a field lab of the WRRC. Using a method described by scientific reviewers as "elegant," two researchers modified a technique known as paper chromatography by substituting glass plates for the paper. A thin layer of a powdered adsorbent was bonded to the plate, which was used in a simple procedure that proved fast, convenient, sensitive, and reliable. First developed in the 1950's to identify the flavoring components of citrus fruit, its use expanded sharply in 1957, when commercial equipment became available in Europe for making the thin-layer plates. Soon it was the most popular chromatographic process, and it was used to analyze inorganic as well as organic materials. One scientist

In 1950, the Eastern lab designed and built the first light-scattering instrument, called a diffusion photometer, for measuring the size of molecules.

commented: "The technique is a nearly perfect, universal analytical tool that allows research workers to obtain answers in minutes instead of hours."

Methods are further modified and improved over the years to meet specific needs. The Eastern lab developed a practical device for carrying out chromatography continuously—an invention which found many practical applications in industry. ERRC also simplified the isolation of fats from food with a dry column method of chromatography. It became the preferred method at the Eastern lab for analyzing dairy products, poultry and eggs, fish, and pet food. In Peoria, researchers made use of high-performance liquid chromatography in monitoring fermentation byproducts in making ethanol for fuel.

In 1950, the Eastern lab designed and built the first light-scattering instrument, called a diffusion photometer, for measuring the size of molecules. The invention was later commercialized under the Brice-Phoenix label and became a standard instrument for studying polymers. In the 1960's, ERRC developed a novel small-angle X-ray scattering instrument that allows scientists to explore such phenomena as the flow behavior of proteins in solution. Recently, the device enabled researchers to explain the calcium-controlled relationships between casein particles and subparticles in making cheese. The research is crucial to the manufacture of better dairy products.

Another important invention of the last 50 years is the scanning electron microscope, which is used to examine the surface of solid objects at magnifications as high as 200,000 times. Unlike an optical microscope, it uses a high-energy beam of electrons instead of ordinary light to form an image. These images, which resemble the picture on a television set, have great depth of field. The scanning electron microscope has been used by regional scientists for countless purposes.

The Southern lab, for example, began using the scanning electron microscope in the early 1970's for direct and detailed observation of the surfaces of cotton fabrics. It became possible for the first time to compare the surface appearances of chemically treated and untreated fabrics, before and after abrasion. A

In 1946 in the Western lab, C.C. Nimmo conducts research to recover tartaric acid directly from grape brandy waste.

More than 40 years later, Peoria chemist David Weisleder uses magnetic resonance imaging to identify pesticides occurring in plant materials.

few years later, SRRC scientists improved the technique by combining scanning electron microscopy with energy-dispersive X-ray analysis. This powerful combination of tools enabled researchers to observe not only the individual fibers of treated cotton, but also precisely where the treating chemicals had lodged.

In Peoria, an examination of 33 soybean varieties with a scanning electron microscope revealed wide differences in seed-coat structure. This unexpected diversity should help soybean breeders to develop varieties with seed coats that resist cracking. Cracked seeds are an open invitation to invasion by microorganisms during storage.

Other new chemistry tools borrowed from physics include infrared spectroscopy, for many years the only instrumental technique available to chemists for molecular analysis. ERRC scientists in the early 1950's used it to study and identify hormones and vitamins, as well as a broad range of steroids related to cholesterol. Later, ERRC devised a new method, called differential isotope shift spectroscopy, for determining the arrangement of carbon atoms in sugars.

One of the most useful research tools is nuclear magnetic resonance, which is also used as a diagnostic aid in human medicine. NMR allows scientists to look at a cross section of a living plant or animal without having to cut into it or subject it to X-rays. The system creates images from low-energy radio waves, which are harmless to the subject. The Western lab built an NMR machine in the 1950's, and the other labs subsequently purchased their own.

At the Eastern center, the techniques have been applied to a study of the enzymes involved in the transport of nutrients in the root of a plant. For the first time, scientists have been able to find out what happens inside a living cell when it takes up nutrients under various environmental conditions. One researcher has said such information is essential "to develop new varieties of crops designed for low-input, environmentally safe farming practices."

Technology Transfer

If you build a better mousetrap, the old saying goes, the world will beat a path to your door. But government inventors will tell you that much of the time, it just isn't so. True, there have been a few instances in which processes or inventions from the four ARS regional labs have been adopted with lightning speed by U.S. industry, but they are the exceptions, not the rule. The Western lab's development of dry caustic peeling of fruits and vegetables is one example of instant acceptance; California canners had been holding their collective breath, praying for a new process that would enable them to meet tough new State standards on disposal of processing wastes. Improved textile processing machinery, invented at the Southern lab in the 1950's, was also adopted quickly. That was a result of the practicality of the inventions and the close working relations between SRRC engineers and the textile industry during the period of development. The same could be said of dehydrated potato flakes, which had been carried by ERRC researchers clear through the pilot plant stage.

In far too many cases, however, it is a painfully slow process to transfer technology developed in the laboratory to commercial manufacture. A 10-year lapse between an invention and its adoption is far from unusual, and occasionally, what looked like a first-class innovation languishes decades later on a laboratory shelf. There may be any of several reasons for slow acceptance. Industry may have such a big dollar investment in current plant and equipment that it hesitates to junk it, even for what might be a superior process. Or it may foresee that a new invention will require years of further development before it is marketable and decide not to take the risk. Occasionally, changing costs of raw materials mean that the product in question can be made more cheaply in some other way. Or the economy may be in a slump and new investment capital hard to come by. Or a skeptical industry may distrust the results of government research, any government research. More frequently in the past, however, an industry failed to adopt a new regional lab invention because it didn't want to share it with other manufacturers.

Until 1980, it wasn't lawful for a Federal research agency to award a manufacturer a license for exclusive use of a Government patent. But Congress in that year passed important pieces of legislation to facilitate technology transfer. Under the Patent Law Amendments, Federal agencies for the first time were granted the authority to award exclusive licenses to private business firms to use inventions patented by the Government.

In a few instances, processes or inventions from the four ARS regional labs have been adopted with lightning speed by U.S. industry, but they are the exceptions, not the rule.

Exclusive licensing means that the Federal Government can give one company—or a limited number of companies—the sole right to use research developed and patented by a Federal agency like the Agricultural Research Service. Without the protection afforded by exclusivity, a company might have little financial incentive to invest heavily in an ARS invention. It takes time and money for an industry to commercialize an invention—and more time and money to establish markets for it. Without the protection of exclusive licensing, another company could take the same ARS-based technology and compete in the same markets without having assumed any of the early risks. As word got around about the benefits of exclusive licenses, the number of applications from industry increased sharply.

The increased attention to technology transfer from Congress and the Executive Branch is attributable in part to foreign competition. Industry in several foreign countries has made good use of U.S.-financed research, including several inventions developed

Working under a cooperative agreement with the Biotechnology Research and Development Corporation of Peoria, Paul Bolen, an NRRC research geneticist, analyzes the DNA of yeasts in a search for new vehicles to move genes from one microorganism to another. "We're beginning to envision a way to create marketable products inexpensively through fermentation, using genetically engineered yeasts," says Bolen.

by the ARS regional laboratories. In too many instances, foreign companies applied ARS inventions before a single American industry adopted them. More than once, foreign industries have sold U.S.-invented products back to us. Congress was deeply concerned about this, as were American scientists.

Some critics complain that exclusive licensing means that research funded by the public is used for the benefit of the few. But without exclusive licensing, some ARS research results might not get to the public at all. When an invention remains unapplied, or is manufactured overseas, no American benefits. When a U.S. business investment is protected by an exclusive license, the public ultimately gets the most for its research dollars. Further, a company must pay a royalty fee to the government for exclusive use of the patent.

The Agricultural Research Service continues to license selected patents on a nonexclusive basis, which means that they are available to any company capable of making and marketing them. With each patent granted, the agency decides whether exclusive or nonexclusive licensing is the best way to get the technology used. The decision hinges mainly on the amount of capital investment necessary to turn the invention into a marketable product.

The major boost to getting ARS inventions adopted came with passage in 1986 of the Federal Technology Transfer Act. This law makes it legal for Government research facilities to accept, retain, and use the funds, personnel, services, and properties of cooperators. In other words, industries can put their money and scientists into an ARS regional lab and work with scientists there to help develop a process or invention into something closer to what industry needs. Also, industries can make advance commitments for exclusive licensing of the products under development. The mechanism provided by the 1986 Act for this new Government-industry cooperation is the Cooperative Research and Development Agreement, or CRADA. As a result, several new and improved products have already reached the market. These include a kit to test for plant viruses, an improved scientific instrument, and a method for in-embryo vaccination of poultry.

One CRADA in Peoria is with a consortium of several major industries and the University of Illinois, who have agreed to work with the Northern lab on research on biotechnology, an exciting frontier for industrial development. The 1986 law encourages this kind of three-way cooperation on research among industry, Federal research facilities, and universities.

Another way to get more technology transferred is to make more information about ARS research known to industry. The agency maintains a technology transfer database called TEKTRAN (Technology Transfer Automated Retrieval System). By early 1991, TEKTRAN contained more than 12,000 brief, easy-to-read summaries of the latest ARS research results, including many from the four regional research labs. These are prepublication notices of research results already reviewed by a scientist's peers and cleared by ARS management. About 400 new findings are added to the ARS database each month. In addition, information on USDA patents is available online from AGRICOLA and by late 1991 was to be added to TEKTRAN as well.

In addition, information about ARS patents available for licensing is published in an Agricultural Inventions Catalog, which is updated periodically. Key inventions are also publicized in press releases, quarterly reports of significant research, and *Agricultural Research*, a monthly magazine published by ARS. The research agency is doing everything possible to make sure that the public knows about key government inventions and processes.

For a time, USDA inventions were licensed solely by the National Technical Information Service (NTIS), an agency of the U.S. Department of Commerce. In response to heavy demand from industry, however, the Agricultural Research Service in 1989 established an inhouse licensing program to supplement the NTIS.

ARS researchers also have new incentives to get their inventions patented. The agency's patent program has been consolidated into a single unit, and scientists now have a much better understanding of the new requirements and benefits of the patent program. Improved opportunities for moving their discoveries into commercial use have stimulated ARS scientists to file more invention reports, the first step in exploring the possibility of securing a Government patent. In 1987, ARS researchers filed 76 reports; in 1988, 139; in 1989, 140. In 1990, with enthusiasm mounting for the new programs, 150 invention disclosures were submitted, many of them from the regional laboratories. Much of this new interest in getting patents stems from the fact that in 1989, ARS researchers earned $60,000 as their share of licensing fees and royalties from their inventions. In 1990, these awards totaled more than $95,000.

There is also a new ARS awards program. Scientists responsible for the successful transfer of new technology, whether patented or unpatented, can each receive prizes of from $500 to $2,500. In 1990, nine ARS scientists were awarded a total of $9,000. There is good reason for excitement about the future of technology transfer.

Naval Stores

For many years, assignments of the Southern laboratory included research on naval stores. The name goes back to sailing ship days, when tar and pitch were essential for building ships. By 1941, when SRRC began its work,

It is no exaggeration to say that SRRC naval stores research revolutionized turpentine processing.

naval stores meant pine gum, rosin, and turpentine. Most of these products were derived from yellow pines in the Southeast, where the industry provided income for some 350,000 people.

It is no exaggeration to say that SRRC naval stores research revolutionized turpentine processing. Throughout the South, farmers stopped using antiquated and dangerous fire stills, substituting SRRC's steam still (Olustee process) for separating turpentine and rosin from pine gum. Besides being safer, the new process replaced the small farmer-owned operations with centralized and more efficient gum processing plants. The turpentine that flowed from the new steam stills was clear as water and of high quality. The product improvements were accompanied by a new system for evaluating pine gum, resulting in higher cash income for farmers.

More research followed, creating a variety of new industrial products derived from turpentine and rosin. For one thing, SRRC researchers developed a more direct and less costly process for making paper sizing from pine gum. The new sizings were of superior quality to conventional rosin coatings for paper. Further, SRRC scientists expanded the market for surplus gum naval stores by making them more competitive in price with other raw materials.

Scientists also contributed to development of simple, accurate methods of analysis for determining the composition of pine gum and rosin. As a result, they were able to isolate and identify the constituents of rosin. One of these, palustric acid, was a new discovery and proved to be an important component of paper sizing.

The Southern lab also found uses for a variety of rosin acids in soaps, paints, varnishes, lacquers, and printing inks. Two compounds derived from turpentine were used in the manufacture of essential oils for perfumes, and still another acid found application in the photographic industry.

Cotton Processing Machinery

An American textile mill at the end of World War II was anything but a model of assemblyline production. With most of its machinery unchanged for decades, cotton processing consisted of many interrelated steps, each of which required the assistance of human hands. A bale of cotton had to travel a long and inefficient route from the concrete floor of the opening room to the spinning frame or weaving loom.

A cotton technologist at the New Orleans lab some 40 years ago describes the sorry state of a cotton bale when it arrived at the textile mill. Before it got there, he says, saws at the gin had separated the lint from the seed and removed some sand and plant trash. The cotton had been compressed repeatedly to bale it, wrapped in burlap, and girded with steel bands.

"At each exchange of ownership in its trade route, the bale is knifed to give up a sample," the technologist recalls, adding that contents of the ragtag bale looked even less promising when it was opened. "Cotton at this stage is a mass of tangled fibers of varied lengths. It contains [dirt], sand, particles of leaf and stalk of the cotton plant, and some seed fragments."

After opening, cotton from many bales was blended, then vigorously cleaned in several operations, damaging the fibers as little as possible. The matter clumps of cotton, "sometimes hard as wood," were then reduced to small tufts and eventually to separate fibers on their way to spinning into yarn.

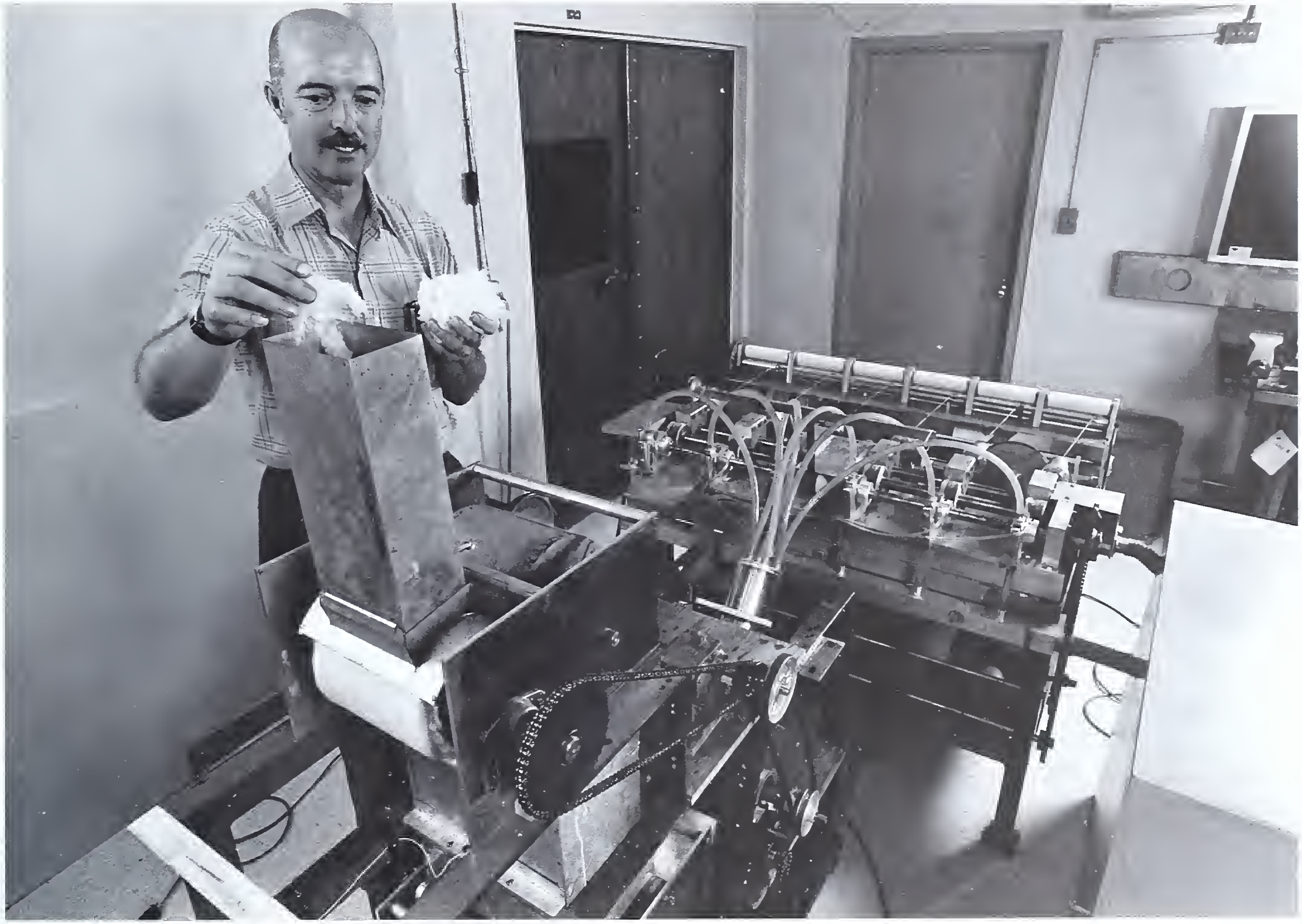
Over the years, the Southern laboratory has made uncounted improvements in every step of cotton processing. These include better machinery, smoother, more efficient processes, and innovative testing equipment. These developments helped save the U.S. cotton industry.

One of the most important early inventions to emerge from SRRC was the cotton opener-cleaner, patented in 1957. With the growth of mechanical harvesting, cotton contained more trash than ever, and cleaning it became progressively more difficult. The opener-cleaner combined the steps of opening bales and blending cotton with more efficient cleaning, producing a smoother-spinning lint. It could process 1,600 pounds of cotton per hour. The first machines were installed in mills within a year, and manufacturers reported savings of up to $100 a day per machine. Farmers benefitted because the opener-cleaner broadened the use of lower grades of cotton.

SRRC engineers soon improved their invention by adding two inexpensive attachments—the aerodynamic cleaner and air-brush doffer. The aerodynamic cleaner increased by one-third the capacity of the opener-cleaner. Together, they removed up to 45 percent of the trash from lint cotton, compared to 30 percent for conventional cleaners. Just as important to mill owners, the SRRC inventions cleaned out much of the so-called pepper trash—tiny bits of leaves and bark that had previously resisted removal.

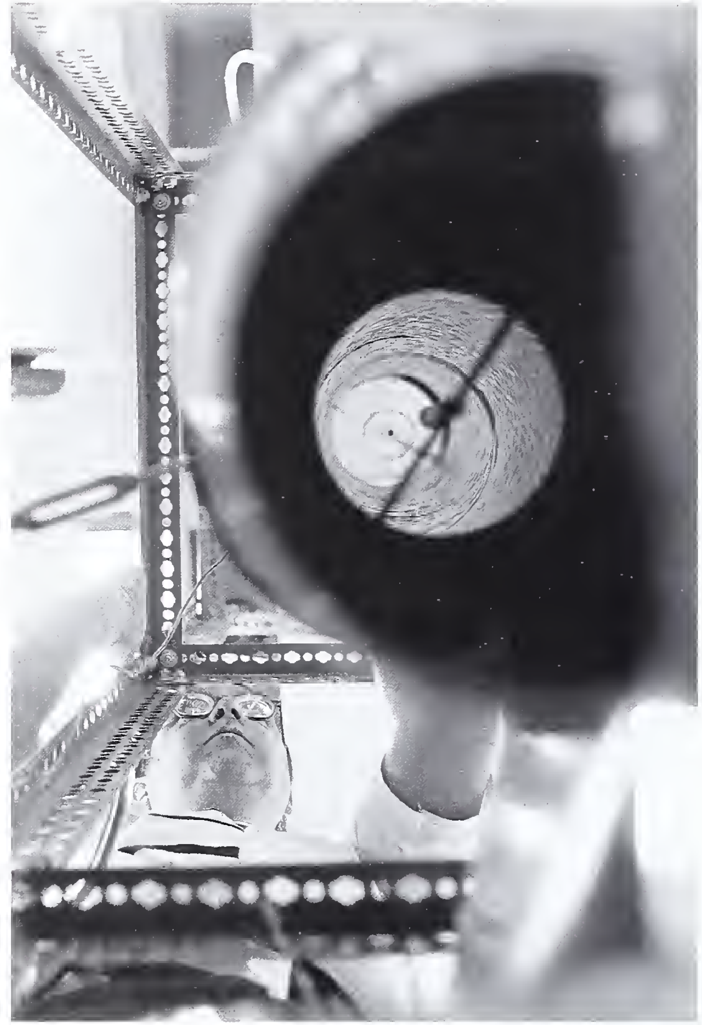
Over the years, the Southern laboratory has made uncounted improvements in every step of cotton processing . . . These developments helped save the U.S. cotton industry.

The next big SRRC invention in aid of cotton processing was the granular card, patented in 1959. Simple and relatively inexpensive, it was the first major change in the cotton carding machine since its invention 200 years earlier. Like the machine it was designed to replace, its purpose was to brush, clean, disentangle, and straighten the cotton fibers before spinning them into yarn. The granular card replaced a carding machine that had an elaborate assembly of brushes and other moving parts. The new carding machine has a rough, granular surface on the underside of a fixed cover. As the cotton passes over this rough surface, pushed along by air currents, its matted fibers are disentangled and smoothed for subsequent spinning into yarn.



Craig L. Folk, an engineering technician in the New Orleans laboratory, feeds tufts of raw cotton into the hopper of a prototype yarn processing system. An electro-optical sensor maintains a constant level of fibers in the hopper, assuring production of continuous, uniform cotton lap.

Modern cotton gin, producing 35 bales an hour, bears little resemblance to outmoded gins of World War II vintage and contains many innovations resulting from SRRC research.



Water swirls down the inner surface of an experimental wet-wall air cleaner, washing away electrically charged particles of cotton dust. The cleaner, tested here by SRRC physicist Devron P. Thibodeaux, uses both electrostatic and inertial forces to control and remove dust in cotton gins and textile mills.

Use of SRRC's granular card cut cotton waste in half. Since it was a sealed unit, it also eliminated a major source of cotton dust in textile mills. The machine was an instant success. One technologist remembers his first look at the new card: "The cotton came out as light as a cloud and just as white. It seemed to float." Within 6 years after its invention, 24 firms had been licensed to manufacture it and 2,500 cards had been installed.

The industry was also quick to adopt a small inexpensive SRRC invention called the pre-opener roll. Its function was to remove the large unopened lumps of cotton from the card and return them to an earlier stage of processing so that they could be reprocessed. Developed at a low cost, some 4,000 pre-opener rolls were installed within 6 years.

The year 1963 saw the invention of the fiber retriever, another inexpensive device that increased the efficiency of the cleaning section of the card by as much as 40 percent. It also removed a high percentage of short cotton fibers and decreased the loss of spinnable fibers, thus improving yarn strength and uniformity. It was also welcomed by industry; more than 20,000 retrievers were in use within 3 years.

Many of the most useful inventions developed in New Orleans were instruments and procedures for testing cotton fibers. New varieties of cotton and new methods of harvesting and ginning caused wider variations in cotton quality than ever before. Also, faster spinning speeds in textile mills and other changes made it more important than ever for mills to know the significant properties of cotton in each bale before blending it with others.

One new testing instrument SRRC scientists named the nepotometer; it predicts the neppiness of cottons. Neps are the small knots of tangled fibers that form during processing. They are tough to remove and one of the many causes of poor fabric quality.

Another tester developed in the 1950's under SRRC contract was the stelometer, which measures the strength and stretchability of bundles of cotton fibers. Yet another was the digital fibrograph to measure fiber length and length distribution with speed and economy. And there have been many other processing innovations from the New Orleans lab.

Some of the more significant cotton processing inventions made by the regional labs . . .

1962—A radically new ringless spinning machine eliminated the time and labor required to change bobbins and rewind yarn. It accomplished this feat by eliminating the bobbin.

1963—Researchers showed that cotton blends containing as much as 5 percent of fungus-damaged fiber could be spun into yarn of satisfactory quality, although spinning performance was lowered.

1966—An experimental machine proved able to blend cotton from as many as 20 different bales at one time.

1970—High-speed motion picture photography enabled scientists to examine the action of textile machinery in extreme slow motion, a big help in designing improvements.

1972—A study showed that raising the temperature and relative humidity in a textile mill could reduce the forces needed to separate cotton fibers by from 35 to 45 percent.

1974—Spiral carding, a new cotton processing system, cut steps in individualizing fibers to allow them to be drawn into a strand and twisted into yarn.

1976—ARS scientists designed, built, and operated a prototype system to process raw cotton stock continuously into yarn.

1979—A no-twist cotton yarn used a liquid binder instead of a twist to hold yarn together. The binder was washed out of the finished fabric when no longer needed.

1985—A new apparatus reduced the amount of hazardous cotton dust in the air in textile mills by removing fine trash and dust from the surface of cotton tufts before the tufts become matted. Foreign matter was trapped inside the machinery. This was a major advance in dealing with byssinosis. Also, Southern lab researchers evaluated yarn samples and conducted production runs to test a high-speed electrostatic spinner, developed under a Federal research contract by the Battelle Memorial Institute, Columbus, Ohio.

Cotton Products: First 30 Years

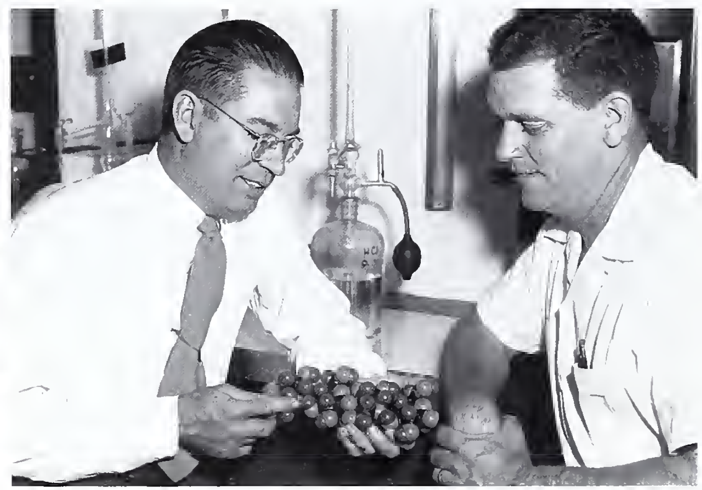
In 1947, when a married woman in the United States was still characterized in magazine articles as "the American housewife," the Department of Agriculture surveyed women on their preferences in fabric materials. The women said they preferred cotton for 11 of 16 ready-made apparel and household items, in some cases by an overwhelming margin.

The 11 items for which they definitely like cotton best were house dresses, anklets, aprons, bedspreads, dish towels, pajamas, curtains, part-wool blankets, nightgowns, raincoats, and tablecloths. In a twelfth category—summer street dresses—cotton tied with other materials. The five items in which cotton lost out to other materials were winter street dresses, hosiery, slips, and short-sleeved blouses. Women who made their own clothes voted for cotton by even larger margins.

The survey results might suggest that cotton in the late 1940's was still king, but the fact is that it was already losing out to synthetics. One of the first severe blows to cotton supremacy came, not in clothing, but in automobile and truck tire manufacturing. A rayon was developed that was strong enough and cheap enough to replace cotton in tire cords. The tire industry's switch to rayon cost growers an annual market for 1 million bales of cotton. Then came men's drip-dry shirts made from synthetics that required little or no ironing. They quickly caught on with travelers and with people who detested ironing. Nylon, sorely missed by women for hosiery during the war years, quickly invaded cotton's markets for all sorts of garments and for curtains and other household items.

Statistics help tell the story. In 1938, and again in 1939, when the four labs were under construction, cotton production was a little less than 12 million bales. In modern times, with twice as many consumers as in the 1930's, production is only slightly higher—about 15 million bales in 1987 and 1988.

Mary E. Carter, former SRRC director, displays washable flame-retardant cotton fabric developed in her laboratory.



In New Orleans in 1955, researchers J. David Reid (left) and Bill Weaver study molecular model of cotton finishing agent.

Cotton in 1947, when so many women voted in its favor, had many inherent virtues, and it still has them today. Cotton fabrics feel good next to the skin; they are soft and comfortable. They absorb perspiration. They launder well; stains come out. And a process developed in the 1930's reduced shrinkage to no more than 1 percent. Cotton fabrics are also durable and abrasion resistant, as military servicemen, wearing cotton fatigues under the most adverse conditions, can testify. Unlike other fibers, cotton is actually stronger when wet, and it is superior to many competitors in acceptance of colorfast dyes. And for countless industrial uses, cotton has been prized for its long flex life; it can withstand repeated bending.

But cotton products after World War II also had some serious shortcomings. SRRC scientists and the industry spent months identifying cotton's deficiencies in the competitive market and then set about to try to correct them with science.

Cotton wrinkled. Cotton is a cellulose fiber; its long molecular chains have no natural bonds, or crosslinks, between them. Cotton fabrics until 1958 possessed only weak chemical bonds that were broken by laundering. Applying heat under pressure (ironing) "mended" the bonds and restored the fabric's finish. That's where synthetic fibers had an advantage over cotton; they were usually designed with cross links built in. And these cross links meant that little or no ironing was necessary. The loss of market to growers and ginners was devastating.

To help cotton growers and the industry hold on to at least part of the shirt market, researchers developed chemical treatments and processes that gave cotton and cotton-blend fabrics the wrinkle resistance of fabrics made wholly from synthetic fibers. The first wash-and-wear cotton shirts appeared on the market in

SRRC research chemist F. A. Blouin removes irradiated cotton from a chemical solution. She will test treated cotton for improved properties, including softness and stretchability.

Cotton Facts

Cotton is the most-used vegetable textile fiber in the world. It is grown on six continents. All parts of the cotton plant are useful. The fiber, or lint, is used to make cotton textiles. Cottonseed produces edible oil and cottonseed meal to feed animals and, in some places, to make flour for human consumption. Linters, the short fuzz on the seeds, are used to make explosives and other industrial products. The leaves and stalks provide fertilizer or are left on the soil to protect it from erosion.

Cotton is cellulose, which is also the structural material found in trees. Cotton cellulose is made of long chains of about 3,000 units of simple sugar, or glucose. These chains associate with each other in a definite pattern and reflect X-rays. This property defines cotton cellulose as a crystalline material.

A pound of cotton contains 90 million fibers. The entire cotton fiber is a single tubelike cell, and its length may be from 1,000 to 3,000 times its diameter. No other vegetable fiber has the spiral form of cotton fiber, and its tensile strength approximates that of steel. Its natural colors are brown, green, cream, and white.

At the Southern lab, durably pressed trouser cuffs of experimental cotton fabric (right) withstood 22 accelerated laundry cycles without damage. Cuffs of conventionally treated fabric showed severe abrasion after only 11 cycles.

1958, with SRRC scientists contributing to their development. These were soon followed by improved clothing made from a new blend of 35 percent cotton and 65 percent synthetic. Finally, in 1965, technology developed at the New Orleans lab made it possible for consumers to purchase all-cotton shirts, pants, and dresses that looked newly pressed after repeated washings. The age of durable press cotton textiles had arrived, providing an annual market for an estimated 2.5 million bales of cotton that would not otherwise be sold.

The research didn't stop there, of course. SRRC scientists kept working to improve their product. During the mid-1960's, they developed a process that doubled the resistance to abrasion of durable-press fabrics. They also invented a chemical finishing process that imparts to durable-press cottons the capacity to dry smoothly when hung on the line while damp. To travelers, the improvement meant no more shirts drip-dripping all night long onto the motel bathroom floor. Other improvements included a host of new finishing and crosslinking agents to make fabrics last longer and resist wrinkling, soiling, and damage by bleaches.

Cotton lacked stretchability. Stretch cottons were developed first in response to wartime military demand for self-clinging, elastic bandages. This was followed in postwar years by increased consumer demand for stretch cotton in diapers, socks, and underwear. In a few years, chemists at SRRC had invented three different ways to put more stretch in cotton.

The earliest method, slack mercerization, uses a relatively concentrated solution of sodium hydroxide (household lye) to impart stretch properties to cotton yarn. The process had its origins in observations made by John Mercer 100 years earlier. The lye solution causes the fibers to twist and crimp, giving cotton its stretch.

In a variation of this method, which was quickly adopted by industry, oversized, loosely knitted socks are made from untreated yarn. The whole sock is then chemically treated, causing it to draw up to about half its original size. When manufactured in sizes 11 to 14, the socks have about 4 inches of stretch.

A second method makes use of resin-forming chemicals similar to those used in producing wash-and-wear fabrics. Cotton yarn is twisted in one direction, treated with a resin, and then twisted in the opposite direction. The back-twisted yarn tries to return to the highly twisted state in which it was treated. In so doing, it pulls itself into tiny resilient helical coils with as much as 200 percent stretch.

A third method treats cotton yarn with a chemical that gives it thermoplastic qualities (the ability to become pliable when heated). The yarn can then be permanently crimped while being heated. This process is similar to that used in making stretch yarns from thermoplastic synthetic fibers. Development of stretch cottons for a variety of uses has helped cotton stay competitive with other fibers and has resulted in millions of dollars of increased farm sales.

Fabrics for outdoor and industrial use are tested on racks outside New Orleans laboratory. Researchers found that weatherability of such fabrics is improved by combining cotton with high-tenacity artificial fibers, like glass.

Cotton lacked resistance to heat, rotting, weather. Not one, but many different chemical treatments were devised in New Orleans during the fifties and early sixties to decrease cotton's vulnerability to attack from weathering, mildew, and rot. The discoveries were used to improve cotton tents, tarpaulins, and boat covers. SRRC scientists also used partial acetylation to make cotton resistant to heat, a development responsible for the sale of millions of ironing board covers.

Cotton was flammable. So many injuries and deaths used to be caused by fabrics catching fire that Congress in 1953 passed a Flammable Fabrics Act, setting mandatory standards for all wearing apparel. The law was strengthened in 1967, and a tougher flammability standard subsequently added children's nightgowns, pajamas, and robes to the list of garments required to be fire retardant.

Initial work at SRRC to develop flame-retardant finishes for cotton was directed at bedsheets, since fires from smoking in bed caused many deaths each year. In 1953, a chemist in the Southern laboratory discovered a compound he called THPC for short. (Tetrakis[hydroxymethyl]phosphonium chloride is its full name.) The researcher found that cotton fabrics treated with THPC did not flare up when held in a flame; instead, they formed a tough black char that retained its fiber structure and strength. The char was thus able to provide flame protection and some insulation. Unlike many other chemicals tested for flame retardancy, the THPC treatment survived laundering and drycleaning. It was used first in military combat clothing, firemen's uniforms, and hospital linens and uniforms. In a short time, flame-resistant finishes, which underwent many improvements, were applied to children's nightwear and many products. Still used today in an improved form, THPC has proved safe, effective, and nontoxic.

Cotton's colors were limited. Before 1957, cotton textile manufacturers used dyeing processes with poor wet fastness and a limited range of attractive shades. SRRC chemists experimented with ways to color cotton by modifying the fibers so they would react chemically with specially synthesized dyes. These experiments led to commercial development of several fiber-reactive dyestuff groups, sold under various tradenames. The process provided textile mills with the means to dye cotton in bright new shades with excellent color fastness and helped improve cotton's competitive market position.

Cotton batting lost its shape. On the market since 1965, a chemically treated cotton batting called Cotton Flote has been much improved over the old-style batting, which became shapeless and lumpy after prolonged use. Developed by SRRC in the early 1960's, Cotton Flote is so resilient and holds its shape so well that it has made cotton batting competitive with all types of cushioning and upholstery materials, including polyurethanes and foam rubber. The material can be treated for fire retardancy.

Cotton lace looked cheap and flat. Before the New Orleans lab developed an improved product in the mid-1960's, cotton lace looked flat and inexpensive. It lacked the handmade, nubby look of fine lace. The new treatment, similar to one developed for stretch cottons, consists of soaking woven lace in a solution of lye, or caustic soda. This causes the fibers to swell and crimp, giving the lace the three-dimensional look of the handmade product. The best news is that greatest improvement in appearance occurs in the least expensive laces.

Technician Anastasia Hammond distills formaldehyde from cotton samples at the Southern lab.

Cotton Products: Last 20 Years

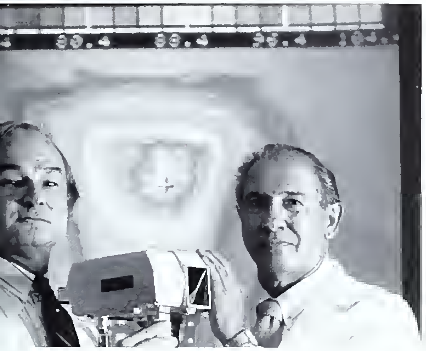
The most important invention of cotton researchers at the New Orleans laboratory during the last two decades is, in the opinion of the Center's current director, a durable-press finish for cotton fabrics that poses no health risk for textile workers. The process, developed during the 1980's, replaces traditional textile-finishing chemicals with new ones that do not release formaldehyde in the workplace.

The Occupational Health and Safety Administration, a Federal agency that monitors the safety of working conditions, has set strict limits on allowable exposure of workers to formaldehyde, which has been identified as a probable human carcinogen. Even though only minute amounts of formaldehyde are released in the process currently in use, the industry would welcome a safer way to impart durable press to cotton.

The SRRC researchers who developed the safer process found a new way to cross-link cotton fibers using citric acid, a polycarboxylic acid. This produces an entirely different kind of chemical bond from that formed during traditional finishing, but one that still forms cross links that reduce wrinkling. One key to the success of the invention over earlier attempts to develop formaldehyde-free finishing is the use of new inorganic catalysts to promote the cross-linking reaction.

The improved process, which keeps cotton fabrics wrinkle-free for more than 100 washings, was patented by USDA in 1990. Several companies quickly applied for a license to commercialize the technology.

Core-yarn Fabrics. Outdoor fabrics that are light, strong, durable, and flame resistant made with core-spun yarn have been developed by SRRC scientists. The fabrics are especially useful for tents and tarpaulins, since their high cotton content ensures breathability and eliminates the sweating and dripping often experienced with synthetics. The core of the yarn is a



SRRC research chemists Tyrone Vigo (left) and Joseph Bruno developed temperature-adaptable fabrics with built-in chemical thermostats. Here they use an infrared camera to measure the surface temperature of a fabric sample placed in front of a heat source.

continuous filament of glass that is wrapped with a blend that is 60 to 90 percent cotton. Fabrics look and feel like 100 percent cotton but are more resistant to sunlight and mildew. Research is continuing to develop specialized core-yarn fabrics for military uses.

Improved Cotton Dyeing. For several years, it was impossible to dye cotton fabrics with durable press properties after their manufacture into garments. This was a matter of concern, since garment dyeing is used increasingly by the textile industry to reduce inventories and to react quickly to new color trends. A new additive, choline chloride, was found by SRRC scientists to render durable press fabrics dyeable with several classes of dyes. The USDA patent for this technology has been licensed. Several other dyeing innovations for cotton fabrics have come from the Southern laboratory in recent years. One is differential piece dyeing, in which the entire fabric is dyed but only selected areas, previously treated chemically, absorb the color. Another patented technique produces a garment that resembles a home-made tie-dyed shirt.

Heat-Transfer Printing. Until SRRC researchers solved the problem, cotton T-shirts could not be printed with those heat-transfer cartoons and slogans that help establish the identity of people who stroll the boardwalks and beaches. The disperse dye, which vaporizes when heated, had an affinity only for polyester fibers. Now cotton fabrics can be chemically modified so that specific disperse dyes used in the design on paper will, when heated, interact with the chemical agent and transfer to the cotton. The chemical also cross-links the cellulose and gives the cotton smooth drying properties.

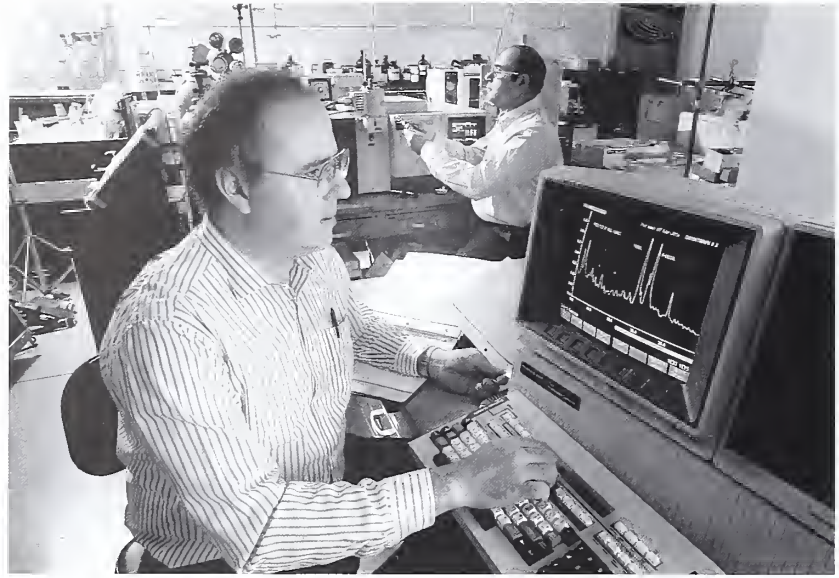
Antibacterial Cotton Fibers. Bacteria that produce body odors or transmit disease can reside and multiply in textile fabrics. This is particularly undesirable in medical clinics and hospitals. No fiber, cotton, wool, or synthetic, has any inherent resistance to bacterial growth. SRRC researchers have developed treatments for cotton textiles with compounds containing peroxides that resist bacteria and, as a bonus, resist fungi that cause athlete's foot. One treatment, Permox, is inexpensive and effective against a variety of bacteria. It can be used on cotton and cotton-blends and will withstand repeated launderings.

Temperature-Adaptable Fabrics. Cotton and other fibers absorb and release some heat. Two SRRC researchers have found a way to attach polyethylene glycols, called PEG's for short, to cotton and other fabrics. Garments so treated respond to changes in temperature; they release heat when it is cool and absorb it when it is warm. The amount of heat that a garment will store and release depends on the kind of fabric material, the chemical applied, and the amount applied. A patent for the process has been licensed in the United States and abroad.

Cotton in Nonwoven Constructions. The nonwoven textile industry, which consumes more than 2.3 billion pounds of fiber a year, uses comparatively little cotton. The three leading fibers are polyolefins, polyesters, and rayons, and they are used to make such nonwoven products as diapers, dusting and wiping cloths, and hospital and surgical gowns, masks, and other disposable items. SRRC research has demonstrated that it is technically feasible to make heat-bonded nonwoven fabrics from high cotton blends. Cotton's most favorable properties of comfort, feel, softness, and absorbency can be incorporated into these fabrics. Waste disposal, a national concern of the heavily synthetic oriented nonwoven industry, is not a problem with cotton, since it is biodegradable.

Cellulose III Cotton Fiber. A fiber developed at SRRC during the 1980's is a rare crystalline form of cellulose capable of improving the resistance to wear of durable press cotton. Derived from native cotton, Cellulose III is highly stable and is permeable by dyes, pigments, and other chemicals used in textile processing. It is created by treating plain cotton cellulose with ammonia vapors and high temperature and pressure until its crystalline structure changes. The alterations in geometric configuration can be observed by X-ray diffraction. It is still a costly laboratory creation, but researchers are looking for less expensive ways to mass produce the fiber.

Wool and Mohair



Chemists William Marmer (foreground) and Paul Magidman analyze wool constituents at the Eastern center to determine effects of chemical and physical treatments.

As wool in the 1950's lost ground to synthetic fibers, researchers at WRRC identified several shortcomings that would have to be overcome if wool were to become more competitive. Wool garments shrank during machine laundering. Wool fibers wrinkled, particularly during travel. Trousers lost their crease. Large amounts of water and energy were required to clean raw wool, and it was yellowed by sunlight. There was also the need to make wool repel stains and retard flames and accept dyeing more readily. Finding solutions to this long list of difficult problems occupied Western wool researchers for 30 years.

After several years of basic research on the nature of wool fibers and many unsatisfactory experiments and trials, a team of Western scientists developed in 1960 a revolutionary method for shrinkproofing wool. In a two-part process, a microscopic film of nylon was bound permanently to the surface of wool fibers. The thin film changed the frictional characteristics of each fiber and allowed wool fabrics to be washed in machines and tumble-dried without shrinking. There was no significant change in the feel or texture of wool products. The technical name for the innovation was interfacial polymerization, but it became known popularly as the WURLAN process. Within a short time, it was adopted by large textile firms in the United States and Europe.

During the next 20 years, new shrinkproofing processes were developed and the original process improved. One new method, perfected in 1978, proved particularly useful for smaller textile operations. It consisted of a one-bath system that applied emulsified polyurethanes to the wool in conventional washing machines. One of the first companies to use the small-scale method manufactured and supplied prosthetic socks to veterans' hospitals.

In another shrinkproofing process, wool fibers were exposed to a low-temperature electric glow discharge, which not only made the woolen fabric shrink-resistant but also more receptive to certain dyes. Yet another technique made fabrics simultaneously shrinkproof and stain-repellent.

"The creasing of wool fabrics . . . involves the same general principle as giving hair a permanent wave."

Credit—or blame—for popularizing sharp creases in men's trousers is said to belong to Edward VII of England, who started the fashion in the second half of the 19th Century during his long tenure as Prince of Wales. But Edward had a valet whose job it was to press his trousers. It was not until the early 1960's that a WRRC team found an acceptable way to provide ordinary citizens with wool trousers that had built-in creases that could survive even rainy weather.

A WRRC scientist described the process very well. "The creasing of wool fabrics," he wrote in 1962, "involves the same general principle as the permanent waving of hair. Fibers are exposed to a chemical solution that penetrates their internal structure and unzips chemical linkages that tie together the web of threadlike molecules. The separated molecules can now slip past one another when the assembly of the fiber is strained, as during the pressing of a garment. New chemical crosslinks are formed almost immediately between the molecules in their new positions." The process was quickly adopted by the U.S. military to put permanent creases in uniform trousers.

ERRC chemist Christopher Carr monitors bleaching reactions on samples of urine-stained wool.

After conducting flame tests on wool, Mendel Friedman, WRRC research chemist, compares fabric on left treated with chemical flame retardant with untreated fabric on right. The treated fabric charred slightly but wouldn't ignite.

Mohair, the hair of Angora goats, underwent laboratory modification in 1969 under the influence of a strange piece of apparatus. A textile chemist studied what happened when he passed mohair fibers through the atmosphere between two electrically charged plates. The electrical device, called a corona reactor, was built at the Western lab to modify fibers from sheep and goats chemically. What the reactor did to mohair was to remove the fiber's slickness, a property fortunately lacking in wool. The slickness of untreated mohair fibers makes them difficult to handle during carding, spinning, and other steps in converting raw fiber into finished textiles. In ways not entirely understood, passage through a corona field brings about chemical changes in the surface layers of mohair, making the fiber more tractable during processing.

During the 1970's, Western lab researchers experimented with several ways to make wool flame-resistant. Most successful was application to the fabric during dyeing of a chemical known as TBPA, short for tetrabromophthalic anhydride. The new treatment was economical, nonirritating, and long-lasting. Further, it impaired neither dyeing nor mothproofing. Tests of TBPA treatment by a major wool carpet manufacturer showed that it far exceeded flame-spread standards for hospital use. An Oregon manufacturer reported that his firm had adopted the treatment to make wool blankets flame-resistant.

WRRC chemists were responsible for several innovations in dyeing wool. Perhaps the most significant saved time and energy by allowing wool to be permanently dyed in 1 minute or less. The process called for continuous dyeing in a hot (135°C to 150°C) ethylene glycol dye bath. Traditional dyeing required boiling wool in a water dye-bath for an hour or more. Also, under the right conditions, the hot ethylene glycol treatment can impart two-way stretch to woolen fabrics.

WRRC chemists were responsible for several innovations in dyeing wool. Perhaps the most significant saved time and energy by allowing wool to be permanently dyed in 1 minute or less.

In 1983, wool research was transferred from the WRRC to the Eastern center at Wyndmoor. ERRC scientists and U.S. wool growers were concerned because unacceptably high contamination of domestic wool with urine-stained and black-pigmented fibers led to frequent downgrading of the product. One reason for the poor showing is that U.S. growers raise sheep primarily for meat: in many other countries, sheep are bred and raised mainly for their wool. Dual processes are available to industry to bleach both types of discolored fibers, but the expense of conducting two different bleaching steps has made industry turn away from American-grown wool in favor of whiter imports. Now in a new ERRC-developed process, both stains and black fibers can be bleached in a single bath, saving time and energy for the textile maker. The chemical also costs less than bleaches used in the second step of the old dual process. The result is a very white wool, free of pigmented and stained fibers and competitive with foreign imports.

Leather and Hides

A multitude of problems confronted the U.S. leather industry in the 1940's and 1950's. Well over half of America's shoes were being soled with nonleather materials. A variety of fabrics and synthetic materials were being used for the uppers. In addition, industry practices were often careless and wasteful. Far too many hides were spoiled by improper handling and curing before they reached the tannery. Others were damaged by insects and parasites.

Inside tanneries, researchers from the Eastern lab found little uniformity in the way leather was made. Many tannery processes were slow and outmoded. Remarkably little was known in the industry about the chemistry of tanning; those in the trade simply knew from experience what had worked in the past.

New formulas for coloring and dying leather were badly needed, as were better tanning compounds. And one of the most

Saving Leather-Bound Books

Library of Congress officials a few years ago were looking for better ways to preserve rare books bound in leather. Too many bindings were drying, cracking, and crumbling. Variously blamed for the damage were exposure to light, excessive dryness or humidity, and sulfur dioxide in the air. Librarians turned for help to the ERRC, where three researchers developed a brand new formulation—a silicone emulsion to mat down and heal the abraded areas of aging leathers. The formula also prevents water or oil from entering or leaving the leather. The bindings will require periodic treatment.

ERRC chemist Frank Scholnick shows examples of leather cured with short zaps of ultraviolet light or electron beams. Curing leather with radiation is nonhazardous, nonpolluting, and more energy-efficient than conventional leather finishing with solvent chemicals.

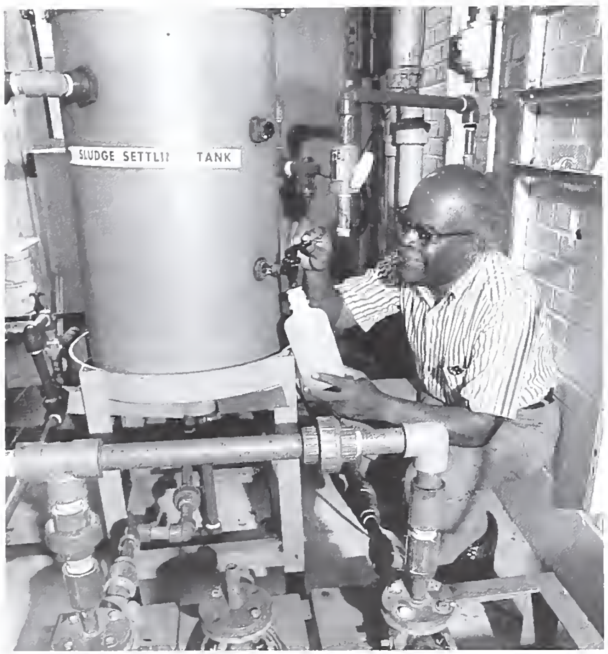
pressing needs was for ways to dispose safely of tannery wastes. Pollution of streams by the leather industry, observed the 1939 USDA research survey, "is daily becoming more acute and urgent."

Obviously, there was much work to be done, and over the years, ERRC scientists have made discoveries and improvements in practically every area of leather chemistry and manufacture. One of the most important came in 1956, with development of a new tanning agent—glutaraldehyde. It produced a softer, more durable product than tanning with chrome, and it was resistant to the adverse effects of perspiration and chemicals. It also proved compatible with all major tanning agents.

The glutaraldehyde process was first adopted commercially in 1958, just 2 years after its discovery. By 1965, some 30 U.S. firms were using the new tanning agent, mostly to tan the upper leather in shoes. In time, they found other applications, including tanning deerskin to make it easier to stitch. One use that proved of special benefit to bedfast invalids was the manufacture of shearlings, which are sheepskins processed into leather with the cropped wool remaining on the skin. Shearlings had long been used to line suede sheepskin coats but lost ground over the years to synthetic fibers. Recently, however, the genuine article has started to gain in popularity.

When tanned with glutaraldehyde, shearlings resist the detanning action of water and deterioration from alkaline chemicals. These properties led hospitals in the 1960's to use shearlings to prevent and cure bedsores. The wool was placed in direct contact with the patient's skin, where it quickly absorbed and dissipated perspiration, providing the patient comfort and promoting healing. In tests in several hospitals and nursing homes, the shearlings retained their original shape and resiliency after repeated launderings in heavy-duty hospital washers and dryers. They could be used for as long as 28 months. Today, shearlings and leather tanned with glutaraldehyde continue to be used for such disparate purposes as bedpads, golf and batters' gloves, and paint rollers.

In the 1980's ERRC engineers built a 150-foot-long, two-story continuous-beamhouse processing pilot plant at the Wyndmoor laboratory. The project was part of an accelerated effort to upgrade tanning technology in the United States. The beamhouse is where hides are prepared for tanning by cleaning and soaking them, removing the hair, and, in the case of cattlehides, splitting them. The procedures followed in the typical beamhouse had remained virtually unchanged for centuries and were described by ERRC engineers as "laborious and inefficient." The new pilot plant automated these age-old processing operations. It also made unnecessary the many manual batch steps that expose beamhouse workers to noxious chemicals. Recently, with research completed, the Wyndmoor pilot plant was sold and installed in a commercial tannery.



Developing a more economical process to treat sulfide-laden tannery wastes, Joseph Cooper, an ERRC research chemist, collects biosludge from settling tank. He will then examine a sample under a microscope to determine the efficacy of microbes in the anaerobic treatment system.

The ERRC also developed a way to apply finishes to leather with quick bursts of ultraviolet or electron beam radiation. The process, unlike conventional curing and finishing methods that use lacquer, is nonpolluting, since there are no solvent fumes to escape into the air outside the plant. Further, the equipment is safe to operate; built-in shielding protects the workers.

The process ingrains finishing chemicals into leather as it moves through radiation equipment on conveyor belts. Many different colors and textures are available. Radiation curing saves at least 60 percent of the energy cost of conventional leather finishing, which requires the slow evaporation of solvents in 100-foot-long drying ovens. Scientists anticipate further savings in plant space and labor. The system has been tested in commercial tanneries. Like the automated beamhouse, it is part of a long-term research project aimed at returning a competitive edge to U.S. leather industries.

During the 1970's, an ERRC team of chemists found a way to marry leather to plastics, creating a chemical bond between protein molecules in the leather and a molecule of plastic. The process, known as graft polymerization, results in a stronger, higher quality product that is more receptive to dyes.

ERRC scientists have also come up with a new treatment for tannery wastes that contain sodium sulfide, a toxic chemical used to dehair hides. A compact, oxygen-free reactor uses bacteria that eat the waste. Chrome shavings, which are formed when leather tanned with chromium sulfate is trimmed or buffed, also pose a worsening waste problem. Landfill operators today are increasingly reluctant to accept the shavings, fearing eventual contamination. A new process developed by an ERRC team employs a bacterial enzyme commonly used in laundry detergents to separate the chromium in the shavings from the animal protein in the leather. The chromium can then be filtered out to form a solid chromium cake. It now seems likely that the chromium can be treated chemically so that it can be reused by the tannery. In addition, the protein product left behind after the chromium is removed may prove a bonus; it has potential as an animal feed additive or fertilizer.

Salt, which is used to prevent spoilage in fresh hides, is one of the leather industry's most serious environmental pollutants. Wyndmoor scientists developed an experimental curing method in which acetic acid and sodium sulfate replace the salt. The cure not only reduces the amount of salt waste by about 97 percent, but it also produces cattlehides that make better leather.

Saline pollution has been further reduced by relocating the initial steps of leather manufacture closer to packing plants in the South and West. The moves permit uncured hides, known as blue stock, to be taken directly to tanneries without first salting them or packing them in brine. The change came about in part as a result of a joint study conducted in the 1970's by ERRC researchers and USDA economists.

After passing through the first of three conveyors in the pilot plant for continuous beamhouse processing, a hide with hair loosened by chemicals is ready for the unhairing machine. ERRC mechanical engineer Wolfgang Heiland operates the control panel, moving the hide to the second conveyor.

A sample of finished leather from the continuous beamhouse is checked for quality by James C. Craig, ERRC chemical engineer and project leader.

Unlike most tannery wastes, one byproduct of leathermaking has turned out to be useful—even to save lives. Collagen, a fibrous protein found in the offal that accumulates when hides are prepared for tanning, is colorless, tasteless, odorless, and nonallergenic. ERRC researchers have developed several purified collagen products from unused parts of the hides. They include food and cosmetic ingredients and an artificial skin that helps burn victims heal.

Certain tannery pollutants occasionally pose a hazard to tannery employees as well as to the public. The air in several tanneries was found to contain a dangerous amount of a nitrosamine, a cancer-causing substance. A team of ERRC scientists, already experienced in tracking and preventing nitrosamines in food, quickly determined the source of the air contamination in the tanneries. It was produced when diesel exhaust fumes from forklift trucks combined chemically with a compound used to unhair hides. The problem was eliminated by replacing the unhairing chemical with one that wouldn't react with chemicals in the exhaust.

Scientific detective work also tracks down the cause of hide and skin defects that each year ruin all or part of many hides. One type of leather, for example, appeared normal but broke under the stress of shoe manufacture. ERRC researchers traced the weakness to a genetic defect in a strain of Hereford cattle. The answer to the problem will have to come from crossbreeding or selective breeding.

In another instance, large numbers of scaly, scabby hides were turning up from several southwestern States. ERRC scientists linked the defects to an insect outbreak. As a result, ranchers in the Southwest began using appropriate insecticides. ERRC leather detectives also traced cockle, a seasonal defect of sheepskins, to infestations with keds, a parasitic insect. After it was demonstrated to sheep producers that keds not only lowered the value of the skin but also caused sheep to grow more slowly, sheep farmers began treatments to decrease or halt the infestations.

Milk and Dairy Products

The chief contributions of the Eastern laboratory to milk research have been to improve and safeguard processed dairy products, to modify them to expand consumer use, and to increase our fundamental knowledge of milk's chemical and physical properties. The use of milk in the United States today continues to be almost entirely for nutritional purposes. Nearly three-fifths of the milk produced in this country each year goes into processed foods, including cheese, butter, ice cream, and

other dairy products. Milk-derived nonfood products developed by ERRC scientists and others have generally not proved competitive in price with comparable products made from other raw materials.

One of the first ERRC invitations to be widely applied by the dairy industry was an improvement in canned evaporated milk. As far as the industry was concerned, the preferred method for sterilizing concentrated milk was the high-temperature, short-time (HTST) process, which did the job in from 3 to 15 seconds. But there was a problem: Evaporated milk made the HTST way tended to gel in the can if stored too long at room temperature. While the thickening was harmless, consumers were understandably disturbed when the milk wouldn't pour from the can. Processors reluctantly abandoned the HTST method.

Then, in the 1960's, an ERRC dairy products team found that gelling could be prevented for a much longer time in HTST-sterilized milk by adding polyphosphates to stabilize the milk before canning. The stabilizers, which were already used in processed cheese, extended the gel-free shelf life of evaporated milk by from two to six times. The practice was soon adopted throughout the industry and is still in use today.

Wyndmoor scientists also developed an economical way to remove off-flavors from milk without overheating it. (The objectionable flavors came from the plants the cows grazed in certain seasons, such as wild onions.) The ERRC method brought milk to the required pasteurization temperature by steam injection; it was then deodorized by flash cooling in a vacuum chamber. Any volatile flavors in the milk were removed in the vacuum chamber, along with the water added as steam during pasteurization. In conventional deodorizers, milk had to be heated to 195°F or higher to eliminate off-flavors.

The ERRC deodorizing process was adopted by cheesemakers as well as by processors of market milk. The method permitted cheese milk to be pasteurized, deodorized, and increased in concentration by 8 percent in one continuous procedure. This allowed the capacity of a cheese plant to be increased without installing more vats. The research, which was relatively inexpensive, resulted in savings of millions of dollars for processors within 2 or 3 years.

Before 1960, many of the bacterial starters used in making cheese were attacked by viruses known as bacteriophages, which either slowed the growth of starters or killed them. ERRC researchers developed a phosphate-and-heat treatment for the milk used for preparing starters. It effectively prevented bacteriophage activity. Within 5 years, half the cheddar cheesemakers in the United States were using the process.

An improved dry whole milk with 3 percent butterfat was also developed in the 1960's, using a new vacuum foam process. ERRC engineers first introduced fluid milk into a vacuum at low temperatures to concentrate it. Nitrogen gas was injected to transform the fluid milk into a foam. The foam was then spray-dried. Because the milk was dried gently, at low heat, the flavor was altered so slightly that many people were unable to tell the whole milk reconstituted from powder from fresh milk. Market tests in the Philadelphia area indicated favorable consumer response to the product, and the product may yet be marketed.

Another innovation of the 1960's was lowfat ripened skim milk cheese. At the time of its development, there were no reduced-fat, semihard cheeses on the retail market, despite considerable consumer demand for such products. The outcome of many experiments by an ERRC team was a low-fat, high-moisture, semisoft cheese that resembled cheddar in texture and flavor. Its fat content, however, was only 6 percent, compared to 33 percent for Cheddar; its protein was higher—30 percent versus only 24 percent for Cheddar. The process was commercialized.

Peoria food technologist George N. Bookwalter pours a cup of low-cholesterol milk made from frozen concentrate.

Thanks to lab research at the Eastern center, a wide range of dairy products is available today for the many consumers unable to digest milk sugar, or lactose.

Research at the Western laboratory during the 1980's led to a new chemical test that cheesemakers can use to make sure their cheeses are properly aged and ready to sell. Commercial dairies could automate the procedure and use it to check such products as Cheddar, feta, and Monterey Jack.

For several decades, research to unravel the mysteries of milk proteins has been conducted at the Eastern center. As part of this fundamental research, caseins, the major protein in milk, were separated by a simple method into three individual proteins, designated alpha, beta, and gamma. Relative amounts of each protein in milk were later found to vary genetically with the individual cow and the breed. The genetic variations could be related to a cow's yield of milk, the milk's total protein, and the total yield of cheese, and the data could be used in breeding cows with higher, more nutritious milk production.

The proteins in casein are so complete nutritionally that they are a standard by which other food proteins are evaluated. Nevertheless, proteins other than casein, found in the whey portion of the milk, contain even more of the essential amino acids. They include alpha-lactalbumin and beta-lactoglobulin. Research on these proteins revealed that they also vary genetically. The laboratory's findings on the chemistry of milk proteins has led to important new insights into their use as highly nutritious food ingredients. Several scientists involved in basic and applied research have been recognized with Borden Awards for milk chemistry and dairy manufacture and with other prizes.

One piece of ERRC research in the early 1980's created a whole new group of consumers for milk and milk products. Throughout the world, countless people suffer from a deficiency of the enzyme lactase in their digestive tracts. As a result, they are unable to digest lactose, or milk sugar, which is fermented to undesirable compounds and gas by intestinal bacteria. The condition is much more common among black people, Asians, and native Americans than it is among Caucasians, and it is more common among adults than children.

Wyndmoor researchers used lactase from nonhuman sources to break down about 70 percent of milk sugar into the simpler sugars, glucose and galactose. Most lactose-intolerant people could drink this modified milk and digest it without discomfort. Scientists then demonstrated that treated milk could be used to make milk products, such as ice cream, cheese, and yogurt, that were equal to or superior to untreated products. The results of the research were first made available to the public by a firm in New Jersey. The company's president reported that more than 100 million servings of lactase-treated milk and dairy foods were consumed in 1985 by enthusiastic new customers of the dairy industry.

New ARS Dairy Drinks

New milk drinks have been concocted at three regional labs. One of these, Orange Velvet, combines milk and orange juice and was blended cooperatively by ERRC and a dairy products firm. It has scored well in market tests in the Washington, D.C., area. The Wyndmoor lab has also come up with tasty vanilla and chocolate shakes that contain only half the sugar of conventional shakes. They were designed as an alternative to the fluid milk requirement for a Type A school lunch.

In New Orleans, an ARS food technologist combined water, nonfat dry milk, and juice or fruit flavoring, and then bubbled carbon dioxide through the mixture. The carbonated milk combines the nutritional values of nonfat milk with the flavor and fizz of a soda.

In Peoria, two NRRC researchers have invented a frozen milk concentrate with no more cholesterol than skim milk. They combined nonfat dry milk with a little water and vegetable oil (cholesterol-free) before freezing. The milk is said to reconstitute well, and taste panels liked it. It also makes a tasty whipped topping that stays foamy for 24 hours.

ERRC engineers Edward Schoppet (left) and Howard Sinnamon evaluate macaroni enriched with high-protein whey for dough consistency, uniformity, and appearance.

Whey

Nine pounds of whey, a watery byproduct of cheesemaking that contains about half of the nutrients of milk, are produced for every pound of cheese. It is to the credit of the scientists of the Eastern center and to other researchers that new uses for whey have been discovered during the last 50 years to accompany sharp increases in U.S. cheese production. While whey continues to be a surplus product, more than 40 percent of it is now marketed each year, and research continues to find new and profitable markets for the product. Were it not for research, the industry would have to get rid of hundreds of millions more pounds of unused, surplus whey annually, a financial loss as well as a serious waste disposal problem.

In general, there are two kinds of whey: sweet rennet whey, produced in making Cheddar and other sweet-type cured cheeses, and sour or acid whey, from cottage cheese, farmer cheese, and similar products. Even before 1940, USDA researchers had begun working with the dairy industry to find uses for sweet whey. They were successful in helping create markets for a large part of it in sweet bakery items and in fudge and other candies.

Sour whey is more of a problem. Years ago, it was often dumped in streams, where its high oxygen demand made it a serious water pollutant. In 1961, ERRC scientists invented a better way to spray-dry dairy products. Selected gases were injected under pressure into the high-pressure feed line of a conventional spray dryer. The resultant foam dried quickly into a fine powder that could be reconstituted easily with water. The process worked well with cottage cheese whey, which had been difficult to dry with the unmodified equipment. The dried acid-type whey is used to a limited extent in several dairy, bakery, and pharmaceutical products.

Kevin Hicks, ERRC chemist, led research team that developed an inexpensive way to obtain lactulose, used to treat a liver disorder, from whey, a surplus commodity.

In the same year, an ERRC team led by a biochemist found a way to use whey to produce a yeast. With a generous supply of oxygen to keep the process going, half a pound of yeast was produced every 5 hours from each pound of whey sugar. The yeast contained 50 percent protein and was similar in its content of amino acids and vitamins to other yeasts used in foods and animal feeds. Wheast, as it was called in the Wyndmoor lab, was produced for a number of years by a California company.

Pioneering research at ERRC in 1968 resulted in a new way to reduce pollution and produce nutritious food ingredients from whey. Millions of pounds of whey were still being fed to pigs or were dumped into streams and lakes, and the dairy industry needed better ways to handle it to comply with new antipollution legislation. ERRC research, both in Wyndmoor and through contracts, demonstrated the economic feasibility of removing water from whey with a process called reverse osmosis. It was already being used (and still is, in the Middle East, among other locations) to make fresh water from sea water.

Application of another process called ultrafiltration led to production of high-protein concentrates with the nutritive value of egg white, the highest quality protein. Whey protein concentrates are produced routinely today on a commercial scale by ultrafiltration. In addition, reverse osmosis units are gradually replacing thermal evaporators in plants as an economical means of removing water from whey.

In the early 1970's, a nutritious blend of dried whey and soybean flour replaced nonfat dried milk in the Food for Peace Program. It was developed at a time when dried milk was scarce and priced out of reach for the Title II food donation program. The whey product was designed as a dietary supplement for preschool children in developing countries. ERRC scientists and industry engineers worked together to move the product into commercial production, and millions of pounds of the whey-soy blend were shipped to feed malnourished children before dried milk again became available for the food program.

ERRC scientists in the 1970's boosted the nutritive value of pasta by enriching it with protein fractions derived from whey. The protein in unenriched wheat flour is nutritionally deficient in lysine, an essential amino acid that is a constituent of whey. Adding whey to spaghetti and macaroni enhanced their amino acid balance and increased their total protein content. Engineers found that as long as at least 60 percent of the added protein was denatured, or made insoluble, through heat coagulation, conventional equipment for processing pasta could be used without modification.

In the early 1980's, ERRC chemists found an inexpensive way to make a hitherto expensive noncaloric sugar—lactulose—from whey. Lactulose is used to treat a serious liver disorder.

Thanks to continuing research, about 1.5 billion pounds of whey are sold each year. A large portion goes into human food, including dairy products, prepared dry mixes, soft drinks, infant foods, candies, and bakery goods. It is also used in pharmaceuticals, often in the form of lactose. An even larger share of whey goes into feeds for cattle, swine, and household pets. And industry experts believe an expanding market exists today for whey protein concentrates, not only in pasta but in other foods as well.

Sugars and Sweeteners

A book or two could be filled easily with details of the research on sugar and sweeteners at the four regional centers during the last 50 years. Depending on their location, scientists worked with cane and beet sugars, corn sugar and syrup, sorgo, honey, maple syrup, milk sugar, and any number of specialized sugars and sugar byproducts. They also searched for ways to use waste products of the sugar industry, like bagasse, the residue from cane after it is pressed. And during World War II, at the Northern lab, they found a simple, inexpensive way to produce sugar from wheat.

Shortly after the United States entered World War II, a shortage of cornstarch ensued because so much corn was being diverted to the manufacture of industrial alcohol. Cane and beet sugar were also scarce, and sugar had to be rationed. NRRC researchers therefore turned to wheat and wheat flour as a source of sugar, since both were plentiful in 1942. In a surprisingly short time, they developed the batter process for extracting wheat starch and gluten. The starch was easily converted into two sugars—glucose syrup or dextrose. Commercial application of the process resulted in wartime production of millions of pounds of sweeteners.

Southern researchers developed ways to make specialized sugars for the candy industry.

Another wartime phenomenon was the abrupt doubling of demand in 1944 for lactose, or milk sugar. This resulted from the commercial production of penicillin, which required a growth medium developed at the Peoria center including corn steep liquor and lactose (see "Penicillin and the War Years," p. 5). The need was met largely by increasing production of lactose from cheese whey. New plants had to be built and existing plants expanded, but thanks to industry-government cooperation, new production goals were reached in just 5 months.

After the war, the Southern laboratory turned its attention to helping the sugarcane processing industry with its many needs, including higher cane yields per acre and juice with a high sugar content. SRRC research soon proved to growers and the processing industry that fresh cane, delivered to the sugar mills immediately after harvesting, yields a higher percentage of recoverable sugar than cane left lying in the fields after cutting.

Southern researchers also developed two processes for making specialized sugars for the candy industry. One, turbinado sugar, was made directly from cane juice during harvest without refinement by bone char or carbon. The process was inexpensive and could be installed and operated efficiently at any desired scale of production. The other method, which involved ion exchange, produced sugar whiter and purer than turbinado. The product proved suitable for candies like mints where a white color was necessary.

Another process invented at the Southern lab made it possible to produce a new product, aconitic acid. This is a nonsugar component in Louisiana sugarcane blackstrap molasses. Aconitic acid had been known for 75 years as the principal organic acid in sugarcane, but until SRRC worked on the problem, there had been no practical way to separate the acid from the molasses. Once the separation process was perfected, SRRC scientists demonstrated that chemicals derived from aconitic acid could be used in molding transparent plastic materials and as wetting agents in emulsions and cleaning compounds. Costs of recovering the acid from the blackstrap proved low in relation to financial returns from sales.

WRRC research in the 1950's and 1960's led directly to three changes in the diffusion process for making beet sugar. The first controlled the formation of unwanted lactic acid during the process, reducing sugar losses from 0.3 percent to less than 0.1 percent. A second change, patented in 1961, rearranged the piping on sugar beet diffusers to recover sugar previously lost in the pulp press water. Used by industry since 1961, it cut sugar

After analyzing hundreds of samples, ERRC researchers wrote the definitive report on the composition and properties of U.S. honeys.

losses from 3 pounds per ton of beets to 0.6 pounds. A third change, used by the industry from 1957 to 1962, increased the solids content of pressed pulp by neutralizing the supply of diffusion water. Research on all three improvements cost about $250,000; by 1965, their total value to the industry had surpassed $28 million.

Discoveries with far-reaching consequences were made at the Northern center in the late 1970's, at a time when the world price of cane sugar was rising and foreign suppliers were bent on raising the price even more. Unfortunately, known methods for converting cornstarch to glucose either cost too much or produced too little sugar. Careful screening of the fungi in the USDA collection in Peoria turned up a superior strain of *Aspergillus awamori*; using this strain together with a simple change in its growth medium, Peoria scientists produced a fourfold increase in production of the enzyme, gluco-amylase, that converts cornstarch to sugar. This meant that the corn processing industry could meet increased demand for corn sugars without costly facility expansion.

Two other commercially important results came from this Peoria research: Scientists showed that certain enzymes could be immobilized by simple ion-exchange technology rather than the more expensive and costly methods that prevailed at the time. And Peoria scientists were the first to report immobilization of glucose isomerase enzyme, a technique that was later adopted by industry (using a different method) for production of high-fructose syrups from corn sugar.

Research at the Eastern laboratory during the 1980's led to new methods for synthesizing valuable ketose sugars from sugars in surplus agricultural products, like whey. The ERRC process is a general one that can be used, for example, to convert such sugars as lactose, maltose, and galactose into more valuable forms, including lactulose, maltulose, and tagatose. Lactulose is a noncaloric sugar used worldwide by millions of people as a treatment for serious liver and gastrointestinal disorders. Maltulose has been shown to cause less tooth decay than table sugar when used as a sweetener. And tagatose is under study as a possible new sweetener for use by diabetics.

In making these sugars and others, the patented ARS process provides a useful route for synthesis. It can also be used to convert so-called left-handed sugars like L-glucose into L-fructose, a sugar some claim is as sweet as natural fructose but yields no metabolic calories. Recently, a firm in Maryland used the Wyndmoor process to prepare large quantities of L-sugar to allow safety and toxicology studies of this potential sugar substitute.

Another noncaloric food sweetener, discovered in an ARS laboratory at Pasadena, has undergone testing at the Western regional lab. It is a substance called dihydrochalcone, produced by the chemical conversion of naringin, a natural component of citrus peels. It is more than a thousand times sweeter than sugar, but it has not yet been adopted commercially or received approval from the Food and Drug Administration for commercialization.

During a study of adulterants, ERRC scientists discovered a new sugar in honey, resulting from the action of the honey bee enzyme invertase on sucrose.

Yet another sweetener, honey, has been the special province of researchers at the Eastern lab. A report published by ERRC in 1962 remains the definitive study of the composition of American honeys. Hundreds of samples of honey, from known locations and flower sources, were analyzed for sugars, enzymes, effects of storage, tendency to granulate, and other properties. Among other things, the findings made it possible later to detect the addition to honey of low-cost adulterants.

During the study of adulterants, ERRC scientists discovered a new sugar in honey, resulting from the action of the honey bee enzyme invertase on sucrose. The sugar was named erlose, after the Eastern regional lab.

Dextran, Xanthan Gum, and Levan

Three different microorganisms have been found to act on sugars to create three different products with unusual properties. All the products are polysaccharides—a class of carbohydrates that includes starch and cellulose. Their names are dextran, xanthan gum, and levan, and all are remarkable compounds.

It was in the 1950's during the Korean War that dextran was first administered intravenously to battle casualties as an alternative to blood plasma. It is credited with saving thousands of American lives. Economical methods for producing dextran were developed at the Northern laboratory. Dextran's chief advantage over other blood extenders, such as glucose or saline solutions, is that it persists in the blood longer—for days rather than hours. It even has several advantages over blood plasma itself. Unlike plasma, dextran can be sterilized, ensuring that it is virus free. Dextran can also be kept much longer than plasma without refrigeration, and it costs only about one-third as much. Finally, its supply is more reliable. Since it is derived from cane or beet sugar, it doesn't depend on blood donors.

The bacterium that ferments sugar to make dextran is named *Leuconostoc mesenteroides*. Found originally in a bottle of spoiled root beer, it was added to the Peoria lab's renowned collection of microorganisms. When the military made known its need for a blood extender, the bacterium was one of several selected from the collection for experimentation. It worked. Approved quickly for use in military medicine in 1950, dextran in 1953 was also approved for civilian use.

The second product, xanthan gum, is fermented from glucose by *Xanthomonas campestris,* another microorganism (see "Microorganisms," p. 134). Also developed at the Peoria lab, this edible gum has properties that make it ideal for many food and industrial uses. A relatively small amount is able to produce very viscous solutions. That is why it is listed as an ingredient in

The water-thickening property of xanthan gum, used to push out the petroleum that remains in older wells, is demonstrated by Peoria chemist Paul A. Sandford. Solution on left, containing 1-percent xanthan in water, has held sand in suspension for 72 hours; the sediment in plain water on right has fallen to bottom.

practically every salad dressing on the supermarket shelf. It is also found in many other grocery products today.

Another major use of xanthan gum is in extending the life of gas and oil wells that are nearly spent and have stopped producing. A solution of water and xanthan gum is pumped into the earth to push any remaining crude oil to pumping wells. It is also driven in with sand under high pressure to fracture rock in oil and gas wells. And it does the job!

Until recently, there was a problem in getting the xanthan gum back out of the wells without environmental risk. A retired Peoria microbiologist, however, found a microbe in the soil in his backyard that can degrade xanthan gum under the high-temperature and high-salt conditions present in natural gas and oil wells. He and an NRRC chemist have patented the process, which has attracted the interest of oil and gas people in the United States and Europe. Work is now under way to improve the process through genetic engineering of the microorganism.

Another fermented product, levan, is a natural gum made by microorganisms found in soil and in certain plants, including sugar beets. It is a waste byproduct of sugar processing. Scientists at the Southern laboratory, after identifying 28 soil microorganisms that can produce levan from sugar, found one, *Bacillus polymyxa*, that sharply increases levan yields. In fact, reports one researcher, it produces 3 times as much levan from a sugar solution, and in a purer form, than any of the other 27 microorganisms tested.

SRRC scientists are excited by the properties of levan, as earlier researchers were excited by dextran and xanthan gum. With increased competition from lower cost corn sweeteners and noncaloric sugar substitutes, the sugar industry needs to find products of value other than sugar. Levan, say researchers, may be one such product, with potential for use in the printing and cosmetics industries. Some think it could be used like xanthan gum as a thickener or even as a dextran-like blood extender.

Maple Syrup

Maple syrup is a profitable minor crop from Maine to Minnesota. It is valued at about $40 million annually. Produced in late winter and early spring when the sugar maples are dormant, the sap is essentially a weak solution of table sugar plus trace amounts of flavor precursors. (It is these complex precursors, of course, that make maple syrup so uniquely delicious and valuable.)

For many years, the process for converting maple sap to syrup was relatively unchanged from that learned by early settlers from Indians. Research that began at the ERRC as early as 1948 resulted in modernization of every aspect of this farm industry, from collecting the sap to finishing the syrup. Lines of plastic tubing to central collection points replaced the unsanitary open metal spouts and buckets. Germicidal pellets controlled growth of microbes at the taphole, extending the sapflow season and producing larger yields. Processing was improved to produce a syrup free of caramel and other off-flavors, and precision instruments were introduced to control evaporation more carefully. Sanitation in steamy evaporator houses was improved.

In the early 1950's, ERRC researchers developed ways to intensify the natural flavor of maple syrup. The high-flavored syrup contained enough maple flavor and color to permit blending it with less expensive sugar syrup. This technique greatly expanded the maple syrup market.

Other industry improvements followed over the next few decades, including accurate analysis in 1975 of the 25 constituents of maple flavor. That same year, scientists solved the problem of so-called buddy off-flavors in maple syrup, caused by trace amounts of amino acids that form in the early spring, when leaf buds begin to swell. An inexpensive process removed the objectionable flavors. It has been in commercial use since 1977 in the United States and Canada.

Feeds, Forage, and Fodder

A large proportion of the field crops grown in the United States are converted into meat. Feed consumed by livestock and poultry in the United States consists of about 40 percent pasture, 20 percent harvested roughage, including hay and cornstalks, and 40 percent feed concentrates, including feed grains and oilseed meal. Among the concentrates, corn accounts for 62 percent of the total, with other feed grains, including sorghum, oats, barley, wheat, and rye, accounting for 16 percent. The remaining 22 percent includes oilseed meals, animal and fish protein feeds, and mineral supplements.

Among the oilseed meals fed to livestock and poultry, soybean meal is in first place, with more than 90 percent of the market; all the rest, including cottonseed, linseed, peanut and sunflower meal, add up to less than 10 percent. The price of meals to users is based generally on relative protein content and distance from the source of the meal. Cottonseed meal, for example, costs considerably less in the Cotton Belt than it does elsewhere.

Regional research on feeds, forage, and fodders has dealt, among other things, with silage in the East, alfalfa in the West, cottonseed meal in the South, and soybean meal in the North. Chemists have also sought ways to make straw and other cellulose products digestible and to remove or inactivate substances in various feeds that impair their nutritional qualities.

Beginning in the 1940's, NRRC researchers found ways to separate soybean meal into valuable fractions, to reduce or eliminate undesirable components, and to upgrade the meal for animal feeds. At the same time, they found ways to use soy protein in human food and devised new analytical methods to determine and control the quality of soybean meal. The latter research, which was carried forward for several decades, contributed in large measure to making soybean meal first in sales and use among U.S. feed meals.

A lamb eats straw made digestible with hydrogen peroxide, sweetened with molasses, and supplemented with grains. Feeding the test animal are former NRRC biochemist J. Michael Gould, who invented the peroxide treatment, and George C. Fahey, Jr., University of Illinois scientist.

ERRC scientists, responsible for dairy research, also studied animal nutrition. Green animal fodder is made into silage by fermenting it in a silo for use in winter months when feed is scarce. Unfortunately, its nutritional content can vary widely, depending on several different factors. One measure of forage quality is the amount and type of protein in the silage. The Eastern lab developed new methods for analyzing its complex mixture of proteins, and the findings led to greatly improved and longer lasting fodder for cattle and other livestock. Scientists also learned much that was new about the mechanisms of nutrition in beef cattle.

Research began in the West in the 1970's to develop ways to convert rice straw and residues from other crops into digestible feed for livestock. The stems and leaves of crops like rice, corn, wheat, oats, and barley contain carbohydrates in the form of fibrous cellulose, but the cellulose is unavailable to livestock.

An indigestible substance called lignin glues cellulose fibers together and shields them from bacteria in the animal's digestive tract.

WRRC scientists found several ways to make a higher percentage of rice straw digestible, including treatment with high-pressure steam and with steam plus sodium hydroxide, or household lye. Steam increased the digestibility of rice straw from 34 percent to 43 percent, and adding the lye treatment raised it to 61 percent. A few years later, straw was made even more digestible by soaking it in ammonia. Other WRRC experiments on treating crop residues included cooperative work with several universities on corncobs, sugarcane bagasse and pineapple field trash, and seed grass straw.

A major breakthrough in residue treatment came in the 1980's, with the discovery at the Northern laboratory that hydrogen peroxide, an oxidizing agent in common use as a bleach and antiseptic, effectively dissolves the lignin in crop residue so that the digestive bacteria in livestock can reach the cellulose fibers. The oxidizing process can also facilitate the production of industrial-grade ethanol by making the cellulose more accessible to enzymes. Subsequent research showed that the lignin-free cellulose can also be used to increase the amount of fiber in human food (see "Fiber and Cholesterol," p. 107). This chain of discoveries holds promise for practical utilization of a mountain of crop wastes and residues.

Research to remove toxic or antinutritional compounds in animal and poultry feeds has been conducted at several regional laboratories. For example, SRRC scientists worked for many years to find an economically feasible way to remove tiny pigment glands containing gossypol from cottonseed meal. Their presence made the meal toxic to poultry and hogs. Several processes were developed to reduce or eliminate gossypol, including the so-called liquid cyclone (see "Cottonseed Oil and Meal," p. 83). The resulting process is too costly for the flour to be competitive in price with soybean flour.

But soybeans also contain problem compounds. For example, certain soy components inhibit the digestive enzyme trypsin, limiting the nutritional quality of soy products for both animals and humans. Processors routinely toast soybeans at moderately high temperatures to inactivate most of the trypsin inhibitors, allowing soy protein to be used as feed and food.

Research on the same trypsin inhibitors at the Western center has shown that the inhibitors themselves, once they are inactivated, are nutritionally valuable proteins. In addition, one of them is being evaluated for cancer-fighting properties. WRRC scientists have developed monoclonal antibodies that can distinguish among individual inhibitors in soybeans and can be used for fast, accurate measurement of these constituents.

Soybeans also contain a class of indigestible sugars, known as raffinose oligosaccharides, that contribute to poor feed efficiency of soybean meal. These saccharides cause flatulence in animals and in humans. NRRC researchers would like to get rid of these compounds in meal, or, better yet, convert the sugars into something digestible. One research approach is to purify an enzyme, galactinol synthase, that has the potential for controlling the formation of raffinose oligosaccharides in soybeans. The purification is an essential first step in genetically engineering soybeans that do not contain these indigestible sugars.

Phytic acid is yet another antinutrient in animal feeds, affecting monogastric (one-stomach) animals like chickens and pigs. Found in grains and in soybeans and other oilseeds, it is a source of indigestible phosphorus that binds essential trace minerals and protein and lowers the nutritional value of feeds. Since phytic acid is also found in animal wastes, it eventually contributes to unwanted accumulations of phosphorus in the environment.

An enzyme, phytase, is able to break down phytic acid, eliminating its antinutritive property. It also does away with the need for additional phosphorus to be added to feeds. A research group at the Southern center has identified the enzymes responsible for synthesis of phytic acid and its breakdown in soybeans. The team intends to use this information to alter the genes of soybeans so that they will contain lower levels of phytic acid.

A chain of discoveries holds promise for practical utilization of a mountain of crop wastes and residues.

Alfalfa

Alfalfa research at the Western laboratory in the 1940's and early 1950's focused on ways to preserve the vitamin E and carotenoids (precursors of vitamin A) that were lost when alfalfa was dehydrated. After investigating hundreds of compounds, WRRC researchers found that an antioxidant called ethoxyquin was the most effective in preventing the oxidation and loss of alfalfa's vitamins.

Ethoxyquin's safety as a feed additive was demonstrated in cooperative research with industry and State experiment stations. As a result, it was cleared by the Food and Drug Administration in 1959. Just 3 years later, it was being used by 80 percent of the alfalfa dehydrating industry. As usage increased, industry and State researchers reported that ethoxyquin was also effective in preventing several diseases of meat animals and poultry. In 1961, FDA okayed use of the compound as a direct additive for spraying on feed.

A continuing problem with alfalfa, however, was that it contained so much fiber that it was generally limited to feeding cattle and sheep, who were able to digest it. It contained protein to spare, but attempts to separate the leaf protein for other feed uses had been unsatisfactory. A group of researchers in England had developed a product, but it had serious drawbacks, including a dark, greenish color, bitter flavor, insolubility, and poor digestibility. It was a WRRC scientist, seeking ways to modify dehydrated alfalfa for feeding poultry, who discovered that fresh alfalfa can be separated into several fractions. In one process, juice is pressed from fresh-ground alfalfa and heated to 85°C to form a curd of protein, high in xanthophyll, a natural yellow pigment that colors poultry skin and egg yolks. The protein-xanthophyll curd, which resembles cottage cheese, is then separated from the alfalfa solubles and dried to yield a high-protein (50-60 percent), high-xanthophyll product for the poultry industry. The high-fiber residue is a good ingredient for cattle feed. Named the Pro-Xan process, it was first used commercially by a converted dehydration plant in Colorado.

In an alternative process, a differential heat treatment of the alfalfa juice is used to separate a soluble white protein from the green protein fraction. The white protein can be purified to yield an edible product with the whipping properties of egg whites. The remaining green protein fraction can be used for poultry rations.

Chemist George O. Kohler shows samples of pelletized Pro-Xan (left), a poultry and swine feed high in protein and xanthophyll, and dehydrated alfalfa feed for cattle and sheep. Kohler headed the WRRC team that developed Pro-Xan.

Queen of Forages

Alfalfa is the only forage known to have been cultivated before recorded history. Several millennia later, it journeyed with the Persian legions from its homeland, probably Iran, to Greece. As the invaders gained footholds, they sowed alfalfa to feed their chariot horses and fatten their cattle. Persian soldiers ate it, too, boiling the tops for greens or pottage. In time, alfalfa spread from Greece to Rome and eventually throughout most of Europe.

Spaniards brought alfalfa to the Americas, planting it in Mexico and Peru, where arid, alkaline soils were similar to those of the plant's original habitat. Two centuries later, English colonists tried the crop in the inhospitable acid soils and humid climate of the Atlantic seaboard, where it had little success.

It was the California Gold Rush of 1849 that firmly established alfalfa in this country. Several easterners sailing around Cape Horn to the West stopped in Chile, where they obtained alfalfa seed. In California, many found that growing alfalfa paid better than panning for gold. The alfalfa boom was on.

Alfalfa grew rank in California, and its lush growth soon mantled many acres in the intermountain and Great Plains regions. As recently as 1900, however, only 1 percent of all U.S. alfalfa was grown east of the Mississippi. Since then, thanks in part to plant breeders with ARS and State experiment stations, alfalfa has become a national crop. The efforts of breeders were enhanced by the National Foundational Seed Project, which made seed of improved varieties available to seed growers. (Abridged from editorial in *Agricultural Research*, April 1971.)

Alfalfa's history as a nutritious forage dates back thousands of years to the Middle East.

—*Medicago sativa* (alfalfa)

Toxic Weeds

Many range plants are poisonous to livestock, and each year they cost ranchers substantial losses. In research on one of these killers, scientists at the Western laboratory first isolate and identify the toxic chemical in the plant. They then analyze the production of the poison throughout the plant's growing season and let ranchers know when the plant is most toxic. Ranchers can then prevent grazing in areas infested by the weed when the toxin is at a level dangerous to livestock.

As a second course of action, WRRC researchers look for an affordable way to control the weed. It is not unusual for a foreign weed to invade the United States and turn into a bigger pest here than it was in its native habitat. That's because in its homeland, its natural enemies, often insects, keep its population from getting out of hand. When the weed escapes to a new environment in this country, it may well flourish unchecked. One solution, first tried successfully 100 years ago, is to visit the weed's natural habitat, locate its natural enemies, and import them to the United States as agents of control.

In the first category is an American native, locoweed, a notorious poisoner of livestock that has killed tens of thousands of cattle over the years. Ranchers knew the plant was a killer for 100 years before a researcher at the Western center found that the alkaloid swainsonine was responsible for the poisoning. Its identification enabled scientists to predict its occurrence under various conditions and to recommend range management practices to control losses when livestock were exposed to the poison. Discovery of swainsonine has since led to the discovery of related alkaloids. One of these is believed promising in reducing infectivity of the AIDS virus (HIV) and is now being investigated at the National Institutes of Health.

The same WRRC investigator who identified swainsonine in locoweed has also found ways to measure the toxin levels of a class of alkaloids found in groundsels and ragworts, common weeds in the West. These toxins cause cirrhosis of the liver in livestock, but it has been called an iceberg disease since most of its effects are hidden; the animals usually succumb long after they have ingested the plants. Analysis of the plants at various growth stages revealed that toxin levels are at their greatest in the plants in the bud and early flower stages. Fortunately, these are easily recognizable by livestock producers, and they can take steps to keep their animals from grazing them. The analytical techniques developed for these weeds have become standardized internationally for this class of alkaloid, since groundsels cause livestock losses in many countries.

It was 100 years after locoweed was known as a cattle killer that WRRC scientists identified the poison as the alkaloid swainsonine.

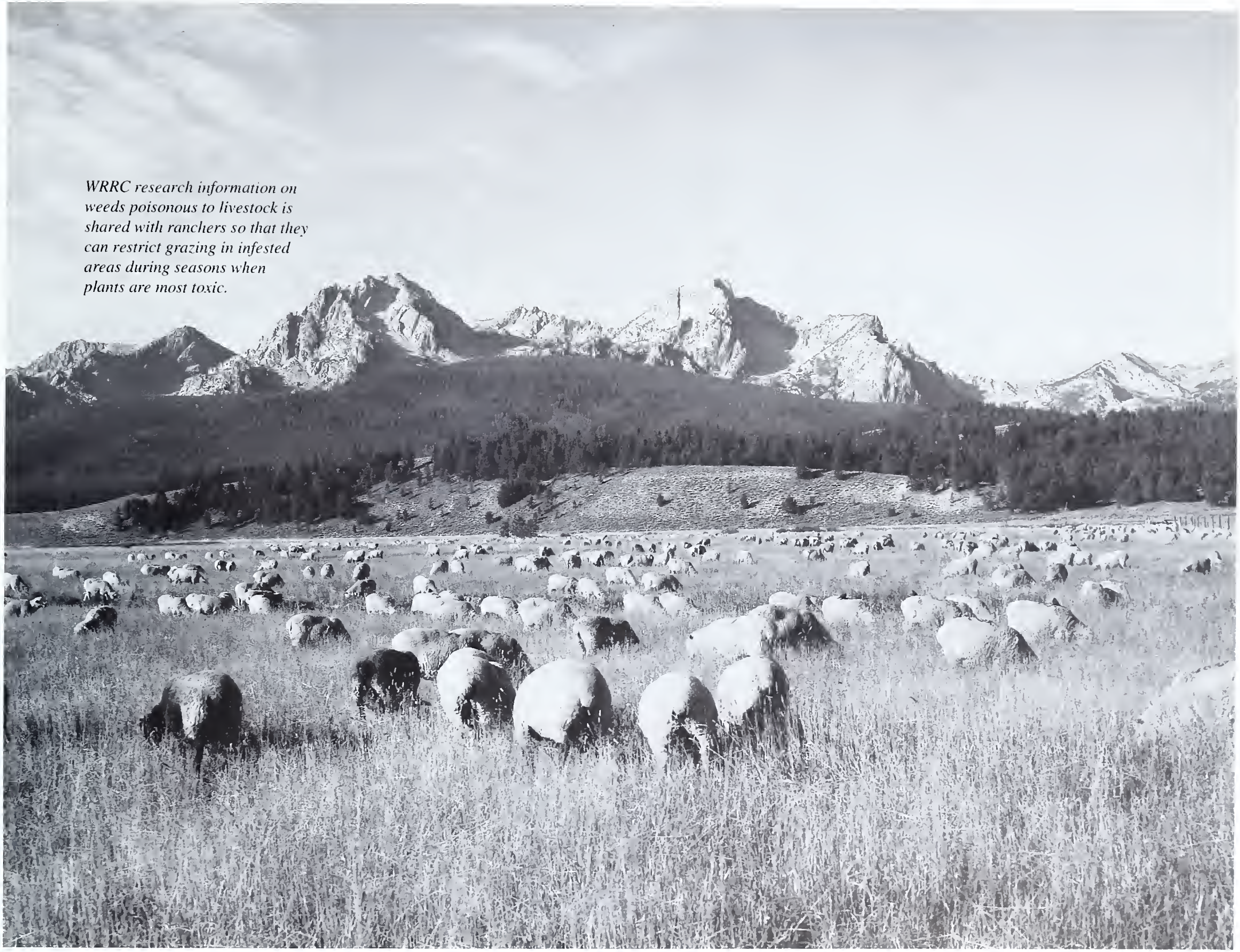
Western lab scientists have also charted seasonal variations in poison levels for tall larkspur, a poisonous plant that grows at high elevations, and for the bur buttercup. The latter plant brought about the sudden death in 1979 of 150 ewes in a fenced pasture in Utah.

In some instances, importation of insects to control toxic weeds has been successful. Two poisonous weeds, Klamath weed and tansy ragwort, ran riot in western U.S. pastures and rangelands after arriving from Europe. Imported insects got rid of 99 percent of both weeds in infested areas.

Recently, WRRC's war on weeds zeroed in on Washington State and Idaho, where 400,000 acres have been infested by a thorny invader, probably from the Middle East. Yellow starthistle, besides crowding out beneficial plants like alfalfa and stabbing the ankles of backpackers, is a horse-killer. The toxin from this plant attacks a horse's nervous system, either killing the horse outright or, even worse, locking up a horse's facial muscles so that it can neither eat nor drink.

So far, five insect enemies of yellow starthistle have been imported. One of the most promising is a hairy weevil discovered by U.S. entomologists in Greece. This is a case, say weed control experts, in which chemical herbicides are too risky or expensive to eliminate the weed.

—*Astragalus mollissimus* (wooly locoweed)



WRRC research information on weeds poisonous to livestock is shared with ranchers so that they can restrict grazing in infested areas during seasons when plants are most toxic.

Eggs and Poultry

In the late 1940's, researchers at the Western lab pulled off a trick that had eluded the U.S. Army's mess sergeants during World War II. They made dehydrated whole eggs, the powdered eggs loathed by millions of men and women in uniform, fit to eat.

What made those wartime dehydrated eggs so unpalatable, it turned out, was the presence of small amounts of glucose in the egg solids. Scientists found a way to remove the sugar by treating the eggs with baker's yeast for 2 hours before the eggs were dried. The process eliminated the off-flavors that had plagued wartime dehydrated eggs. The glucose-free eggs also had a shelf life 10 times longer than the older product. Since the eggs could be used in a variety of packaged items, they began to be used by industry as early as 1950 and led to a substantial increase in the U.S. market for eggs.

A few years later, the Western lab scientists reversed their field and found that *adding* certain carbohydrates to whole egg and yolk powders improved their stability in making cakes and other commercial bakery products. Industry began using these sugared egg powders in 1958.

As 1960 began, certain kinds of bacterial spoilage in shell eggs (eggs sold fresh) were costing the industry about $20 million annually. Western researchers traced the cause to washing eggs in water containing a relatively high iron content of 5-10 parts per million. Despite suspicions that washing eggs might do more harm than good, it was common practice on egg farms to machine-wash all eggs, dirty and clean, to eliminate having to sort them. When research findings were made known to egg producers, they had their wash water tested and stopped using wash water high in iron.

Egg research in the mid-1960's led to methods for adequate pasteurization of egg white. While liquid whole eggs and yolks had been pasteurized for many years, the process had not been applied to egg white because the heat damaged the proteins. Western lab scientists devised ways to stabilize four heat-susceptible proteins in egg white, making it possible to use flash heating to pasteurize the albumin sufficiently to control micro-organisms. The egg white performed satisfactorily in whipping

Conducting experiments to improve the quality of frozen poultry in 1960, WRRC scientists Agnes Campbell and Hans Lineweaver measured tenderness of processed turkey meat.

for meringue and in angel food cakes. The WRRC subsequently published an *Egg Pasteurization Manual* to guide industry, and in 1973, Congress passed a law requiring all processed eggs to be pasteurized.

In 1970, Western researchers demonstrated that reverse osmosis, already used in other ways by the food processing industry, could be used to concentrate egg white for use in making candy and in baking. In another project, WRRC researchers adapted frozen convenience breakfasts originally developed for personnel at Air Force missile bases into products for the civilian market. Now widely available for heating in microwaves, the frozen breakfasts pioneered at WRRC typically include an entree containing at least one egg. Center engineers also helped industry to mechanize the production process for breakfasts.

Other regional labs also contributed to egg research. The Northern lab found that hydrogenated and winterized soybean oil could be used in formulating dried egg mixes for commodity purchase programs. And the Southern lab recently found a fast, simple way to detect spoilage in liquid eggs.

In poultry research, WRRC researchers in the 1960's solved a vexing problem for the processors of frozen chickens and turkeys. Fast, highly mechanized procedures had just been introduced in processing for freezing, and for whatever reason, the result was tough birds. Consumers were complaining, or worse yet, refusing to buy.

Western lab researchers, who had accumulated considerable expertise in freezing fruits and vegetables, discovered that poultry processors were too quick to freeze their birds after they were plucked. Aging poultry at chill temperatures for at least 12 hours before freezing, they found, improved tenderness. Moreover, birds aged before they were cut up were tenderer than those aged afterward. Further, some of the picking machines were beating the poultry too hard, and this also contributed to toughness, as did severe scalding. The WRRC findings were quickly applied by the industry, and consumer acceptance of frozen poultry soon improved. During the next 5 years, consumption of turkey and chickens increased by 2.5 billion pounds.

Meat and Meat Products

Half a century of meat research, primarily at the Eastern center, has focused on improving the flavor, nutrition, tenderness, and safety of meat and meat products. The pursuit of these goals has led to many changes in meat product processing and several new procedures to delay deterioration in quality.

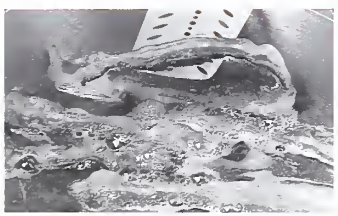
In 1946, the Department of Defense asked ERRC to undertake experiments on the production of canned bacon—a product untreated by heat—that would have a stable shelf life of at least 3 months at 100°F. The other specification was that it would have to smell and taste as good as conventional bacon.

The first step was to find out why all previous attempts to can bacon had failed. ERRC researchers found that the cause of spoilage was the production of carbon dioxide by bacteria known as *micrococci*. Their presence in bacon was normal and expected; it was suspected that they actually enhanced the flavor of bacon. When the bacon was enclosed in a sealed can, however, the *micrococci* produced enough carbon dioxide to swell the cans.

The problem was circumvented by partially dehydrating the bacon during smoking until the ratio of moisture to salt was decreased to five to one. This single change in processing inhibited the growth of the bacteria and provided the stability required by the military. The discovery has been used extensively by U.S. processors to supply the armed forces.

In 1961, another surprisingly low-cost research project at the Eastern center enabled meatpackers to produce more uniform luncheon meats in a more economical manner. When the research began, U.S. packers had adopted computerized formulas for making various sausages that took into account the price and availability of ingredients on any particular day. A shortcoming of the system was the lack of any simple

Intensive study by ERRC scientists of the mechanism of nitrosamine formation in bacon helped avert a proposed ban on this favorite among breakfast meats.



method for determining the ability of meat ingredients to emulsify fat in making bologna, frankfurters, and the like.

ERRC scientists invented a simple test for measuring the emulsifying capacity of a given sample of meat. It produced a numerical value for each sample that could be cranked into the computerized formula. When ERRC demonstrated to meatpackers that the test could be performed by a nonchemist with a minimum of laboratory equipment, it was quickly adopted by industry.

ERRC meat researchers have studied every aspect of meat preservation and quality, asking and finding answers to tough questions. Why does frozen pork turn rancid after a few months in storage? How safe and reliable is the typical farm-cured ham? What proteins make the best binders for fat in making frankfurters? Exactly what happens to meat, from the chemist's point of view, when it is cooked?

That last question led to one of ERRC's most important research projects—one that probably saved an industry. In the mid-1960's, it had been reported that sodium nitrite, an inorganic compound used to cure meat products like frankfurters and bacon, could, under certain conditions, form nitrosamines, compounds known to be carcinogenic. With the aid of highly sensitive analytical instruments, one of these compounds, DMNA (dimethyl nitrosamine) was discovered in extremely small amounts in frankfurters. Another, known as NPyr (nitrosopyrrolidine), was found to occur in minute amounts in bacon after frying at high temperatures. It was the hot frying that did it; the carcinogen was not found in raw bacon at all.

When the results were made public, consumer organizations called for a ban on nitrites in food and a similar ban on sales of bacon. ERRC responded with an intensive investigation of all aspects of the mechanism of nitrosamine formation, bacon processing, and methods of cooking bacon at home. Searching for nitrite substitutes, researchers tried 500 compounds of various sorts as curing agents; 50 of them were active enough as anti-microbial agents in the test tube to warrant testing them in a meat system. Unfortunately, none worked as well as nitrite in retarding the growth of microbes. But researchers also found that vitamins C and E reduced the levels of nitrosamines in fried bacon and in nitrite-cured products. The research led to changes in Federal regulations and industry processing to minimize consumer exposure to nitrosamines. As a result, the proposed ban on bacon was averted, saving hog producers more than $1 billion a year and keeping one of America's favorite breakfast meats on the menu.

Eastern center scientists also studied the source of flavor differences in beef, pork, lamb, and veal and found out what happened to meat chemically when it was aged in storage. They analyzed a traditional Pennsylvania Dutch product, made for years not far from Philadelphia, called Lebanon bologna. They found that it was not the use of old barrels for aging the meat that gave the bologna its distinctive flavor, as even its processors had supposed, but the amount of salt with which the meat is aged.

A scientist's question in the 1980's about processing fermented meats, like pepperoni and Genoa salami, led to a change in making those products. He wondered why most processors didn't use a starter culture to begin fermentation; more than half of them simply relied on the presence of the right kind of microorganisms through chance contact. But the ERRC researcher found that a bacterial starter culture to produce lactic acid stimulates faster, more consistent fermentation and guarantees a better product. It inhibits the growth of unwanted bacteria that can cause off-flavors or, in some cases, food poisoning.

Other researchers turned their attention to making processed meats, like franks and corned beef, with less salt. More and more in the eighties, high dietary sodium was linked to high blood pressure, heart disease, and kidney failure, and most Americans, nutritionists report, eat five to seven times as much salt as they require. But the high salt level in many processed meats was believed essential as a preservative. ERRC scientists wondered, however, how much salt was really necessary as a preservative.

In the mid-1980's, they reported that just about all processed meats could be made with 20 to 25 percent less salt without the risk of spoilage. Lower-salt franks, they found, compared well with conventional hotdogs in flavor, texture, and shelf life. They also discovered that proper refrigeration is more important than salt level in retarding the growth of microorganisms that cause spoilage.

Other regional laboratories have also contributed to meat research from time to time. At the Western center, a chemist developed and patented a 1-hour early warning test to detect spoilage in hamburger. It uses a high-performance liquid chromatograph to measure levels of lactic acid in the ground beef; high levels indicate the meat will spoil quickly. The test is a valuable one for firms that buy quantities of ground beef in bulk: fast-food restaurants, supermarkets, and the military.

A highly original invention to make roast beef more palatable was recently patented by the Southern laboratory. It is a chemical, derived from crabshells, which preserves the desirable flavor characteristics of beef in leftovers. It accomplishes this feat by inhibiting the iron that is naturally present in beef from reacting with oxygen in the air. This prevents the polyunsaturated fats from being broken into compounds that cause off-flavors in the meat. The new miracle chemical, N-carboxymethylchitosan (known as NCMC for short), will also prevent off-flavors in other meats, fish, and poultry, according to the SRRC inventor. It can be applied either during food processing or at home, like any other seasoning.

Reduced-sodium frankfurters are manufactured for taste testing in ERRC laboratory by food scientist Richard Whiting (left) and student assistant Charles Kunsch.

Catfish

Catfish farmers, who are engaged in the fastest growing branch of aquaculture in the United States, had a problem. Their trade association, the Catfish Farmers of America, determined that muddy or musty off-flavors that occasionally develop in farm-fed catfish were the single most serious threat to the growth of the industry. Catfish farmers turned to the Southern center for help.

SRRC scientists discovered in the mid-1980's that it wasn't muddy water that tainted the flavor of the fish. Rather, the large amounts of feed required for maximum fish production resulted in high concentrations of nutrients, mostly nitrogen and phosphorus, in farm catfish ponds. These nutrients, when combined with the heat and intense sunlight of the Southeast, provide an excellent medium for the growth of bacteria and blue-green algae.

The source of the off-flavors was traced to two natural chemicals, geosmin and MIB (2-methylisoborneol), that are produced by the microorganisms. The fish take the chemicals in through their gills, and within 2 hours, they can absorb them in their fatty tissue, making their meat unmarketable. The same two chemicals are often responsible for drinking water with a swampy taste, and scientists are looking hard for ways to correct the problem.

Researchers at SRRC have developed sensitive methods for detecting these off-flavors and are making up test kits for monitoring levels of the two chemicals in drinking water and fish. The work has sparked the interest of water utility officials worldwide. Meanwhile, the search continues to find a way to defeat development of the chemicals, possibly through biotechnology. One scientist explains that "we are just starting to understand the biochemical machinery of these algae."

Until answers are found, some catfish farmers move fish ready for harvest to so-called purge ponds free of algae growth, where it takes at least 2 weeks to flush the off-flavors from fatty tissues. This practice not only delays sales and costs more feed, but fish also lose weight from the stress of moving to a new pond. Most farmers simply hold their fish in growing ponds until the off-flavor disappears.

SRRC researchers helped catfish farmers by finding ways to prevent algae growth in ponds, a source of off-flavors.

Source of swampy off-flavors in some farm-fed catfish has been traced to two chemicals by SRRC researchers, who also developed sensitive tests for early detection.

Animal Fats

The United States is the world's leading producer of animal fats, including lard and edible tallow and inedible tallow and grease. We produce much more of both types of fats than we can consume domestically. In 1988, U.S. production of lard and edible tallow totaled about 1.2 billion pounds; production of inedible tallow and grease came to more than 6 billion pounds. (The latter category is a technical one that means only that the fats cannot be sold for human consumption in the United States. They are exported for a variety of uses in other countries and are used in animal feeds in this country.) U.S. exports of inedible animal fats in 1988 totaled about 2.8 billion pounds, or 45 percent of our total production.

One of the initial assignments of the Eastern regional center was to find new or expanded ways to utilize animal fats, which were then in surplus, as they are today. The most important industrial use of inedible fats 50 years ago was in making soap, which swallowed up nearly 1-1/2 billion pounds of inedible tallow and grease a year. As for edible animal fats, Americans in 1940, still happily unconscious of their cholesterol levels, consumed more lard than they did vegetable oils. Both these uses, of course, have been shrinking during the last half century, and scientists searching for ways to get rid of animal fat surpluses have been fighting an uphill battle. They have been successful nevertheless in finding many new and important markets for animal fats, amounting to hundreds of millions of dollars. And their quest is far from done.

Even while the Wyndmoor laboratory was under construction, its director-designate wondered if ascorbic acid, or vitamin C, might be an effective antioxidant in fat if it were made more fat-soluble. A colleague managed after many difficulties to produce a new compound from the vitamin and a long-chain fatty acid. The result, ascorbyl palmitate, is used today as a dietary supplement and as an antioxidant in vegetable oils. The patent was the first issued to ERRC staff members.

The ERRC team also used hydrogen peroxide to insert an atom of oxygen in the hydrocarbon portion of fatty acids, a process called epoxidation. What the addition of oxygen did was convert unsaturated fats and oils into valuable plasticizers and stabilizers. They blend well with commercial resins, don't evaporate, and minimize the need for other stabilizers, which may be toxic and make plastics hazy or opaque.

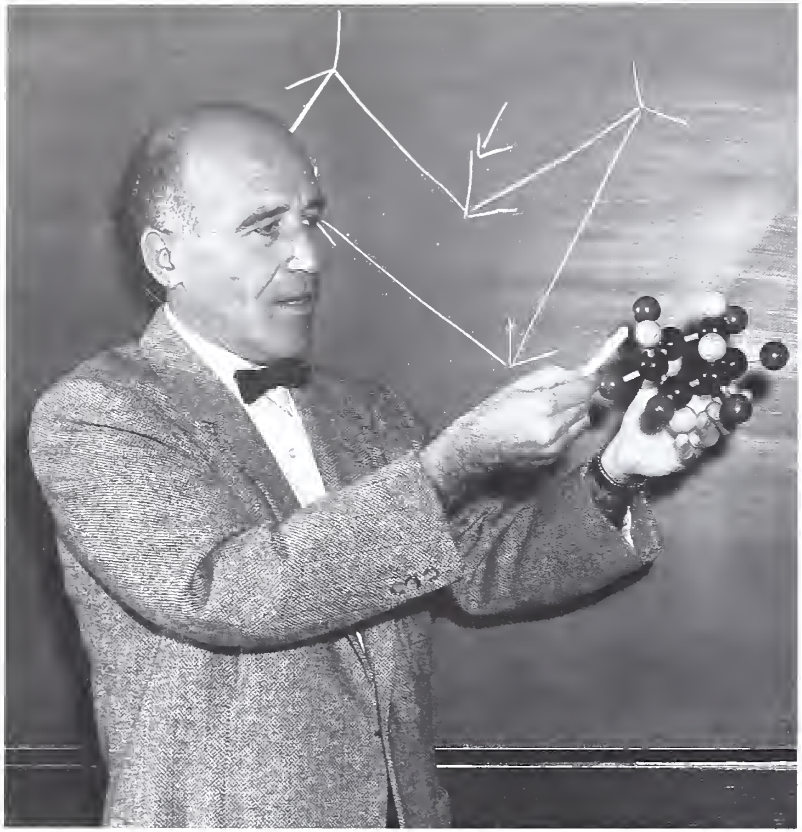
Besides creating a new market for fats and oils, the discovery helped create a billion-dollar plastics industry. Most notably, it transformed vinyl plastics, which were hard and rigid and decomposed in sunlight, into soft, flexible, long-lasting plastics, suitable for floor coverings, auto upholstery, and the 101 other uses of vinyl plastics today. Over the last decade, commercial production of epoxidized ester plasticizers derived from fats and oils has been about 50,000 tons per year. What began as a way to use animal fats, however, eventually turned into a way to use vegetable oils. Some 75 percent of the plasticizers for flexible vinyl today are made from soybean oil.

The greatest single use found by researchers for inedible tallow and grease was in animal feeds. It resulted from a contract sponsored by ERRC and carried out by a private laboratory. The researchers determined the nutritional advantages of including additional fat in dog and poultry feed and developed methods for stabilizing it and incorporating it in the feeds. Other labs later extended the studies of beef cattle, hogs, turkeys, and sheep, all of which were found to thrive on feed containing levels of fat as high as 8 percent.

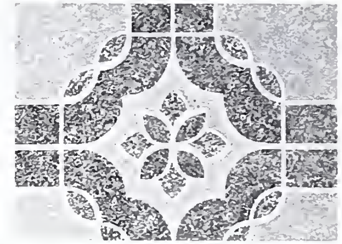
There were other benefits as well. Adding fat to feed eliminated dust, cutting down on the risk of fires and explosions. Fats were also found to help preserve the nutritive value of mixed feeds during storage by reducing the oxidation of carotene, a precursor of vitamin A. A study conducted in the mid-1950's at the Western center showed that after 16 weeks of storage, alfalfa meal lost 62 percent of its original carotene; meal fortified with 5 percent tallow lost only 38 percent during the same period. In addition, the expanded market for fat has meant better prices for livestock producers and packers. Today, animal feeds absorb about 1.8 billion pounds of inedible animal fats a year.

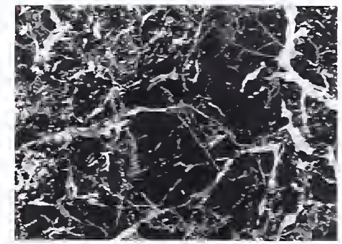
Americans in 1940, still happily unconscious of the health risk of high cholesterol levels, consumed more lard than they did vegetable oils.

Using a process called epoxidation, ERRC chemist Daniel Swern modified rigid vinyl plastics to make them flexible.



Thanks to research by an ERRC chemist, soft vinyl plastics grew into a billion-dollar industry. They are used, among other things, for floor tiles and upholstery.





The U.S. market for edible animal fats was expanded by improvements in blended shortenings. First introduced around 1900, blends were mixtures of cottonseed oil and hard fats, such as lard and tallow. Known as lard compounds, they sold for a lower price than pure lard, then considered the shortening of choice from the standpoints of price and flavor. In the 1920's, however, hydrogenated cottonseed oil began to supplant lard in more and more U.S. kitchens, a trend stimulated by heavy advertising. Lard production and sales fell to a low level—less than 100 million pounds a year up to 1943.

In the 1940's, several publications by USDA chemists described advantages to be gained by a return to blended shortenings. Industry also contributed to a revival of interest in blends by improving the physical characteristics of meat fats, making them more suitable as shortenings. ERRC research showed that blends of meat fats with vegetable oils resulted in products with more stability than meat fats alone, since the vegetable oils contained natural antioxidants. The joint efforts of industry and USDA chemists helped increase the consumption of blended shortenings; the commercial baking industry used large quantities. In the years 1960-65, this use of lard and beef tallow averaged 880 million pounds. Further increases came with the phenomenal growth of fast food restaurants, which used large quantities of blends for french fries.

Unfortunately for the animal fats industry, the major U.S. fast-food chains, responding to widespread public concern over cholesterol, decided in 1990 to switch from blends to vegetable oils. Some estimate the industry loss at 300 to 400 million pounds of edible tallow a year. A number of bakers have also abandoned blends. As recently as 1985, 460,000 metric tons of edible tallow were used domestically for baking and frying; by 1989, that figure had fallen to an estimated 351,000 metric tons, and it is expected to have fallen still more in 1990 and 1991.

A number of manufacturing uses were found for animal fats. ERRC chemists in the late 1940's developed a process for preparing a purified grade of oleic acid from inedible animal fats. The improved acid was soon being made commercially by several of the world's largest producers of fatty acids. Oleic acid is converted to emulsifiers, cosmetic ingredients, and other specialty chemicals and is used in textile mills in lubricants and antistatic agents.

ERRC contract research in the early 1950's resulted in using animal fats as a flux in the hot-dip tinning of steel. To produce a more satisfactory flux, typical industrial grades of animal fats were modified by the addition of fatty acids and by hydrogenation. The new product, which proved a cheaper but satisfactory alternative to palm oil as a tinning oil, eliminated the need for government stockpiles of palm oil, resulting in considerable dollar savings to taxpayers.

In the early 1970's, ERRC scientists conducted research to modify soap in an attempt to recapture at least part of that once-valuable market for animal fats. Unmodified soap is made from fat and lye, which produces soap and glycerine. It has many virtues besides its ability to cleanse; for one thing, it degrades rapidly.

But soap has been eclipsed by synthetic detergents for laundry and other cleaning chores chiefly because it does not perform as well in cold or hard water. Hard water in many parts of the United States gets that way because of dissolved limestone. Unmodified soap and limestone salts form a grainy scum, known to chemists as lime soaps. What a team of ERRC chemists did was add a fat-based compound to keep lime soap in dispersion and to keep it from leaving scum. Not one but several derivatives of fatty acids, alcohols, and amines were found to be effective surfactants for the purpose.

Soap containing 10 to 20 percent of a lime-soap dispersing agent turned out to be a good detergent in hard water, but the chemists decided it wasn't quite good enough. It was made even more effective by the addition of citrate and silicate to act as what detergent makers call builders. After many washing tests, the chemists settled on a 65-15-20 formula for soap, lime-soap dispersing agent, and builder. So constituted, the new detergents worked well in hard, soft, hot, and cold water. In various tests, they outperformed the most effective synthetic detergents on the U.S. market. Further, they contain no objectionable phosphates and are nontoxic to humans, domestic animals, wildlife, and algae. But while the new detergents are now manufactured in other countries, only one U.S. manufacturer has begun to make them—for use so far only in one brand of body soap.

Other ERRC developments have emerged from research on fatty acids. A single-step reaction, known as alpha-anion activation, has produced a wide variety of fatty acid derivatives with potential commercial application. They include a new insect repellant of interest to the U.S. Army and a chemical key to making antidiabetic drugs. Before the new method was invented, the chemicals were either derived through expensive processes or were unattainable by any means.

Eastern lab scientists over the years have developed many innovative methods for analyzing and characterizing the chemical constituents of fats and oils. Many of these methods were tested by other laboratories before their adoption as standard analytical procedures. Once adopted, a method can be used by industry to measure the quality of products containing fats and oils; by trade groups to ensure conformity to international standards, and by researchers to assess chemical changes in fats and oils during processing.

Eventually, several analytical methods were miniaturized at the ERRC so that fatty components of blood and tissue, such

The most important use for surplus animal fats found by ERRC is as additive to animal feeds, including dog food.

as cholesterol, could be investigated. The first analyses of atherosclerotic plaques were performed in collaboration with Philadelphia medical schools using ERRC methods.

Edible tallow is one of the cheapest of fats and is in oversupply in the United States; cocoa butter, used in chocolate, is one of the most expensive and has to be imported. With this in mind, ERRC chemists and engineers have devised ways to separate tallow into fractions of greater commercial value than whole, unfractionated tallow. Several fractions have potential value for the food industry. One has properties almost identical to those of cocoa butter.

Technologists made chocolate bars from the tallow butter, and they report that the candy won favorable scores from ERRC and chocolate industry taste panels. An ERRC pilot plant for making tallow fractions has been scaled up and made continuous, and both the processes and products have been patented in the United States and several other countries. (See also the next section, "Cottonseed Oil and Meal," for a description of related work at New Orleans.)

As the nineties begin, ERRC is conducting research to modify surplus oils with enzymes. Lipases are enzymes that operate on fats, or lipids, which include fatty acids and glycerol. Lipases are being used in laboratory experiments as catalysts to convert low-grade fats and oils into higher grade raw materials. The objective is to produce clear, pure fatty acids and glycerol from spent, discolored, smelly fats and oils. If successful, the clean products can be sold to make cosmetics, drugs, inks, lubricants, and synthetic rubber.

Using a process called hydrolysis, ARS scientists are working on improving a piece of equipment they invented known as an immobilized lipase membrane reactor. Several patents have already been issued in connection with the work, and results—pure, clean fatty acids—are so far promising. A pilot-scale reactor is being built to demonstrate the commercial practicality of the lipase enzyme reactor.

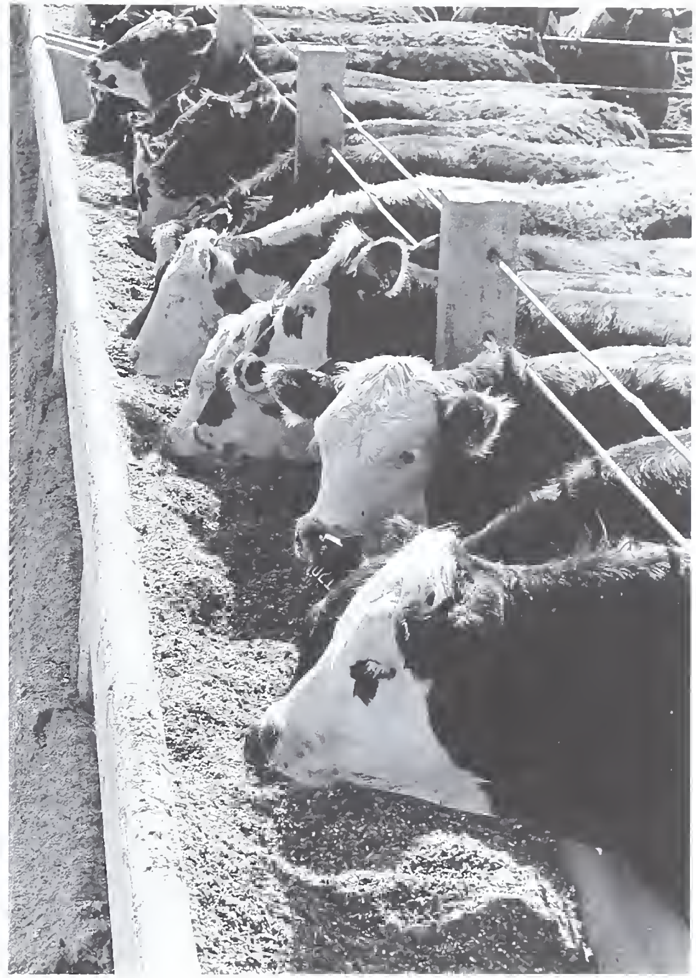
Cottonseed Oil and Meal

The cotton plant produces three important commodities, of which cotton fiber is only one. The other two, both derived from cottonseed after it is ginned, are oil and meal. Cottonseed production in the United States runs between 3 and 6 million tons per year, depending on the size of the cotton harvest. Price fluctuates with production, and the value of cottonseed in recent years has fallen as low as $304 million (in 1985) and risen as high as $718 million (in 1988). About 80 percent of U.S. cottonseed production is crushed for oil; most of the cottonseed meal that remains after oil is extracted is used to feed cattle.

Except for the size of the dollar figures, the words above might have been written 50 years ago, when the Southern center was under construction. Farm production of cottonseed has neither increased nor decreased much since then, nor has production of oil and cottonseed meal. And the meal is still used primarily for cattle feed.

Like the SRRC textile scientists, oil and protein chemists at the Southern lab have had to run very hard for five decades to help keep the cotton industry in about the same statistical place.

Chief reason for the absence of industry growth has been competition from other vegetable oils, just as cotton fiber has suffered from competition from synthetics. Like the SRRC textile scientists, oil and protein chemists at the Southern lab have had to run very hard for five decades to help keep the cotton industry in about the same statistical place. When one considers all that has happened in the last half century, however,



After oil is extracted from cottonseed, most of the meal that remains is fed to cattle.

their achievements have been nothing short of remarkable. SRRC research has led to new or improved methods in every phase of processing cottonseed and contributed materially to the overall operating efficiency of oil mills and to new and improved cottonseed products.

Cottonseed oil was the first domestic vegetable shortening marketed in the United States. Cottonseed had been crushed and oil extracted ever since the mid-19th century. For many years, most of it went into soap. In 1911, Crisco, made from hydrogenated cottonseed oil, appeared on the market. Along with several competing shortenings, it is still sold today. For many years, lard was its only competitor, and when the regional labs began, cottonseed oil shortenings were a well established product.

But there were drawbacks as well as advantages to being an older industry. For one thing, oil processors at the end of World War II had a substantial investment in outmoded equipment. More than half the U.S. cottonseed oil in 1946 was extracted with hydraulic presses, and another 25 percent was squeezed from seed with old screw presses. Change came slowly. At an industry clinic held in 1952, an SRRC scientist described a new cottonseed solvent extraction process called filtration-extraction. It was the first of several new extraction procedures devised in the next 10 years. Some form of solvent extraction is used widely throughout the world today for many different oilseeds.

There were many successes. By 1966, an estimated $533,000 in oilseed processing research in New Orleans had resulted in a cumulative net value added of more than $41.4 million. New products made from cottonseed oil emerged from basic research on fats and oils, creating new markets for surplus oilseed crops. One new group of chemicals discovered at SRRC were acetoglycerides, derived from fatty acids. Some of these new compounds can be formed into thin, stretchable films for a variety of uses in the food and cosmetic industries. Since the films are edible, for example, they can be used harmlessly as lubricants on machinery that comes in contact with food. They are also useful as emulsifiers, plasticizers, and coatings to retard oxidation and moisture damage. Today, six American manufacturers sell more than 1,000 tons of acetoglycerides annually.

Sucrose esters were another chemical invention—doubly valuable because they were made in part from derivatives of two surplus crops: sucrose or table sugar, from sugar cane or beets, and fatty acids from cottonseed oil. The compounds are used today as emulsifiers, stabilizers, and texturizers in baked goods, baking mixes, biscuit mixes, frozen dairy desserts, and whipped milk products. They are also components of coatings for apples, bananas, and pears to retard spoilage, and a highly publicized (but not yet approved) fat substitute appears to be based on SRRC research on sucrose esters.

Cocoa butter, from which chocolate candy is made, is solid at room temperature but melts when placed in the mouth. SRRC scientists chemically modified cottonseed oil, giving it properties similar to that of cocoa butter. (This research is comparable to similar transformations effected with animal fats, mentioned in the previous chapter.) The confectionery fats from cottonseed oil are now being used by the candy industry.

Patients recovering from serious wounds or surgery, and who have to be fed intravenously for long periods, often lose weight when they need their strength most. SRRC chemists developed a high-calorie, nontoxic fat emulsion for intravenous feeding now used by many hospitals for postoperative care. The fat is provided by purified cottonseed oil; the emulsifier is egg lecithin. Patients fed with the emulsion, including wounded military personnel, make satisfactory weight gains and heal more quickly than before.

Cottonseed foots, the settlings from stored crude cottonseed oil, were used to make soap until petroleum-based detergents turned them into a surplus product. SRRC researchers found that treatment with wood alcohol turned the foots into a methyl ester product, now marketed as an additive for high-protein feed.

Haunting the industry, however, like two evil spirits, have been gossypol and aflatoxin. Gossypol is a toxic yellow pigment that is contained in tiny pigment glands no larger than a pinprick. They are scattered throughout the kernel of a cottonseed. While cattle can eat cottonseed meal containing gossypol without ill effects, it is unsuitable for feeding poultry and swine. Chickens fed meal high in gossypol, for example, lay eggs with pink whites and green yolks. A major aim of SRRC research, therefore, has been to expand the market for animal feeds by getting rid of the gossypol.

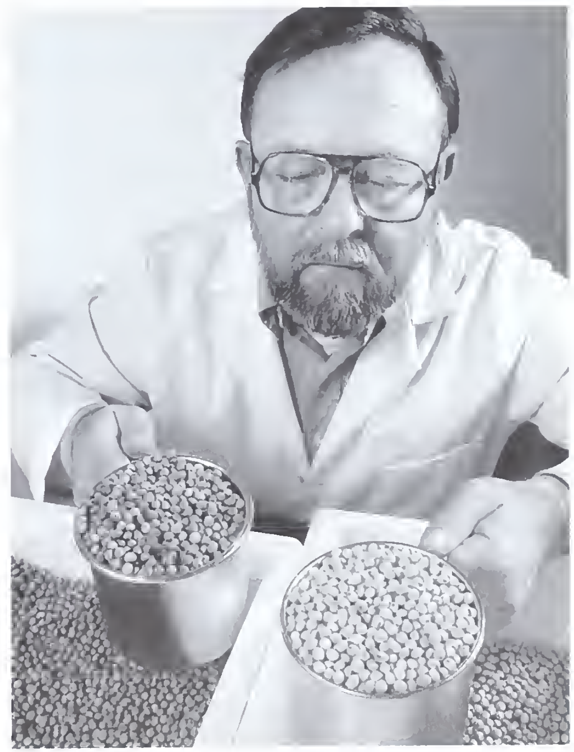
Aflatoxin, a potent carcinogen created by two molds that can grow on cottonseed and other commodities under certain environmental and storage conditions, has also occupied researchers in the Southern lab since its effects were first observed in the 1960's. Aflatoxin posed a serious problem for cottonseed processors, who were unable to market seed and meal because the extent of contamination was not known. SRRC scientists developed reliable analytical methods for aflatoxin detection and provided standard samples of aflatoxins. These became the official analysis methods for oilseeds and have been used for 20 years by oilseed processors to guarantee a supply of toxin-free products for feed (see "Food Safety," p. 97).

One answer to gossypol was the liquid cyclone process, invented in New Orleans in the 1950's. Agitating the seeds in a solvent such as hexane separated cottonseed meal into two fractions. One fraction, which contained very little gossypol, could be ground into a high-protein cottonseed flour for human consumption. The other, containing 50 percent protein and most of the gossypol, still made a satisfactory feed for cattle. Satisfactory flour and poultry feed were produced from the process, which has been tried on a small scale in this country and abroad, but competition from other products has so far prevented widespread adoption.

So has discovery by a California ARS researcher of a glandless cotton containing little or no gossypol. It has so far been unpopular with many growers, who report lower yields and insist that the absence of gossypol leads to increased insect damage to the cotton. It appears likely that toxic gossypol is a natural defense of the cotton plant against insect pests. Enough glandless cotton is currently planted, however, to supply a plant in Texas that manufactures cottonseed flour, and this industry could expand in future years with increased world demand for protein. Cottonseed flour is a highly nutritious product with up to 70 percent protein, and it can be added to almost any food without changing the taste or texture.

Soybean Oil

A Peoria research scientist aptly referred to the soybean of 50 years ago as the "the ugly duckling" of U.S. agriculture. It was certainly that. When Congress created the four regional research centers some 50 years ago, lawmakers couldn't have guessed at the spectacular future that lay ahead for that hard little bean from Asia, then a minor crop grown mostly for forage. Contrary to all expectations, the soybean within a few decades would become the Nation's second biggest row crop, the second biggest cash crop, and the biggest export crop. It would also grow into America's number one source of vegetable oil and of oilseed meal for livestock and poultry.



NRRC chemist Gary List contrasts dark, low-quality soybeans damaged by weather with high-quality soybeans that can be processed with a minimum loss of oil.

In 1938, the U.S. soybean crop was an insignificant 62 million bushels, harvested from about 3 million acres. During the 1980's, an average of 2 billion bushels of soybeans were being harvested each year from 60 to 70 million acres, with the annual value of the crop to farmers exceeding $10 billion. Never in the history of this country has a crop increased in importance as quickly as has the soybean. And it was scientific research, much of it conducted at the Northern center in Peoria, that helped transform the ugly duckling of forage crops into the swan of high-protein feeds and vegetable oils.

In the 1940's, a chemist recalls, soybean oil made neither a good industrial paint nor a good edible oil. Shortages of cooking fats in World War II had forced processors as a last resort to add it to margarine, but even then, their upper limit was 30 percent. The flavor of soybean oil in those days was variously described by consumers as "grassy" or "beany" or "fishy," and it tasted even worse after it had been stored for awhile.

Without too much enthusiasm, Peoria researchers set out to improve soybean oil as much as they could. They decided that as an essential first step, they would have to establish some uniformity of judgment about how various soybean oils tasted. They selected taste panels and had panelists rate the flavors of soybean oil with numerical values instead of with imprecise adjectives. These more objective methods for assessing flavor and odor meant that the ratings of panelists in one processing plant could be compared with those in another plant and that panel results could be reproduced elsewhere. A scientist observes that while this early research may sound trivial, "it turned out to be the first significant milestone in improving soybean oil."

Guided by judgments of taste panels, NRRC researchers identified the source of many of the off-flavors in soybean oil as trace metals, particularly iron and copper. Even extremely small amounts of these contaminants sped oxidation of the oil, shortening its storage life and promoting undesirable flavors. Responding to these findings, industry removed brass valves in refineries and substituted stainless steel for the cold rolled steel in equipment that came in contact with soybean oil. These actions alone improved the flavor of the oil.

Guided by judgments of taste panels, NRRC researchers identified the source of many of the off-flavors in soybean oil as trace metals, particularly iron and copper.

Another improvement followed the end of World War II in Europe. Warren H. Goss, a chemical engineer from the Peoria laboratory, was commissioned in the Army as a major and ordered to follow Gen. Patton's tanks into Germany to investigate the German oilseed industry. The rumor was that during the war, the Germans had somehow succeeded in making soybean oil palatable. When Goss reached Hamburg, he found what he described in a letter home as "a strange process" for stabilizing soybean oil. Without doubt, it improved the odor and flavor of the product, but it consisted of many arcane steps, including repeated washings and mysterious chemical treatments. Goss took the details of the process back to Peoria, where nearly all of the complex refining steps were found to be useless. One step, however, the addition of citric acid to the deodorizer, was what made the German process work. The discovery that citric acid would deactivate the trace metals in soybean oil soon led to finding many other chemicals that could do the job. Industry response was prompt, and today practically all soybean oil is protected during processing by citric acid.

But questions remained unanswered. Metal contaminants could speed the development of off-flavors, but chemists wondered what caused the flavors to develop in the first place. The answer turned out to be linolenic acid, a fatty acid that makes up from 7 to 9 percent of soybean oil. That is about double the proportion in other vegetable oils, and it is this constituent that was causing soybean oil to turn rancid on the shelf or when it was heated repeatedly in deep fryers.

After long and often disappointing research, Peoria investigators discovered a "highly selective" copper-chromium catalyst that would enable processors to remove much of the linolenic acid. In the process, hydrogen was bubbled through the oil (hydrogenation) to combine with the fatty acid and solidify it. Presence of the catalyst assured that large amounts of the linolenic acid could be solidified selectively, leaving other, more desirable, fatty acids in liquid form. The oil was then chilled and the solidified linolenic acid removed.

While some features of the NRRC process have been adopted by the soybean industry, others remain unadopted to this day because of their high cost. But the NRRC discovery that it was linolenic acid that caused soybean oil to go bad spurred plant breeders in ARS and state research facilities to develop soybean lines with lower linolenic acid content, a work that continues to this day. Breeders have been aided in this search by an NRRC analysis of more than 15,000 soybean samples for oil and protein content, including content of linolenic acid. Important research to breed better soybeans is conducted in several places today, most notably in ARS labs in North Carolina and Indiana. Several promising new lines of soybeans have already been bred with linolenic acid content as low as 3.5 percent. A new approach, begun by an ARS scientist at Purdue, concentrates on breeding lines that lack the enzyme responsible for oxidizing linolenic acid.

Another early research breakthrough came in the 1950's, with discoveries about so-called hidden oxidation in soybean oil after it was deodorized. The cause was found to be oxidation compounds in the oils that decomposed during deodorization of the oil and formed new compounds that brought about undesirable changes in flavor and stability. Peoria recommended certain alterations in processing the oil before deodorization that overcame the problem. From the 1950's on, production of soybeans and soybean oil—and exports—began to climb off the charts.

Many other improvements in soybeans and their oil have been made at the Northern lab. An oil additive that combines two compounds—methyl silicone and citric acid—was found to lower the odor intensity of heated soybean oil. In recent years, evaluations by taste panels have made it clear that the implementation of improved processing techniques and protection of the oil during processing produces an oil that is stable during storage. Hydrogenation of liquid soybean oil produced in this careful way and treatment with antioxidants does not improve flavor stability during storage. Hydrogenation is still required, however, for the use of soybean oil as a high-temperature cooking oil and in shortenings and margarine.

When the regional labs began, soybeans were a minor crop, grown mostly for forage. Today they are the Nation's second largest cash crop and the number one U.S. export crop.

To determine the frying and baking performance of soybean oils low in linolenic acid, NRRC food technologist Kathleen Warner (foreground) and technician Linda Parrott compare foods cooked with genetically modified oils with those prepared with commercial vegetable oil products.

Soybean Facts

Soybeans contain 20 percent oil and 40 percent protein. Through processing, they yield oil, lecithin, a 50-percent-protein soy flour, and dietary fiber. The flour can be further processed into a 70-percent-protein concentrate or a 90-percent-protein isolate.

Food ingredients derived from soybeans are listed on hundreds of labels of supermarket products: margarine; salad dressings; cooking oils; breads; pastries; all manner of cake, muffin, and biscuit mixes; tuna fish; meat extenders; breakfast cereals; soy sauce; diet foods; and many others.

NRRC research during the last half century has helped solve many problems that confronted the food industry when they tried to use soybeans in foods. Obstacles to utilization that were successfully overcome included off flavors and odors, short shelf life, dark color, and many processing difficulties. The net result of the research is that soybean byproducts have become the most versatile and ubiquitous component of processed foods today.

In the mid-1980's, an NRRC team found that deterioration of the flavor of soybean oil exposed to light could be reduced by adding as little as 5 parts per million of beta carotene, a natural food color and a precursor to formation of vitamin A. This discovery was also widely adopted.

Metabolic data from stable isotope tracer experiments with human subjects have provided NCAUR scientists with a biochemical basis to evaluate the nutritional value and health effects of dietary fats. Information based on isotope tracer studies and human tissue analysis led researchers to conclude that concerns about the adverse nutritional qualities of hydrogenated soybean oil are over-exaggerated.

Metabolically, trans acids are not equivalent to saturated fatty acids and all saturated fatty acids are not metabolically equivalent. Information from similar isotope studies found that the human body can meet its needs for omega-3 fatty acids by converting dietary linolenic acid in soybean oil and canola oil into the same beneficial omega-3 fatty acids in fish oil.

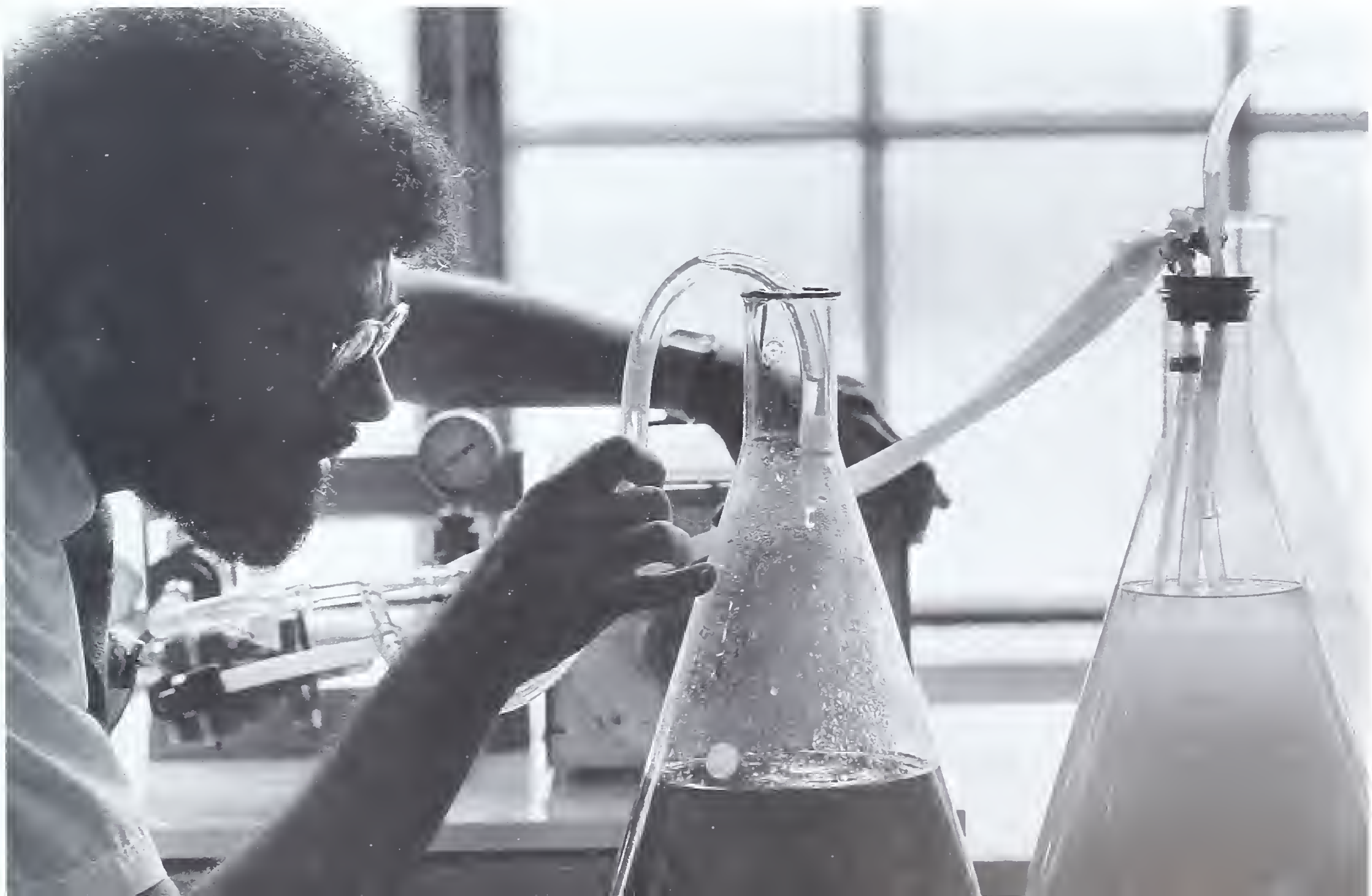
An NRRC research team discovered in 1990 that tuning up crude soybean oil with sound waves can produce a better salad dressing. Very high frequency sound waves, known as ultrasound, get rid of gummy impurities at much less cost than current processing methods. Taste panels were unable to distinguish oil refined with ultrasound from the conventionally processed kind.

In another kind of research, Peoria scientists found that the risk of dust explosions in grain elevators could be reduced or eliminated by treating corn, wheat, and soybeans with soybean oil. One year after treatment, there was no significant impact on grain quality, including odor and germination, or on grain handling properties.

Vegetable Oils in Industry

Like animal fats, domestic vegetable oils, including soybean oil, are excellent sources of many industrial chemicals. The chief reason that more such products are not used by U.S. industry today is the competition from petroleum products, which are generally cheaper. Secondary competition comes from the 2.5 billion pounds of vegetable oils imported by the United States each year, including large amounts of coconut oil, castor oil, and palm and palm kernel oils. As a result, only a fraction of U.S.-produced vegetable oils today are used in manufacturing and for other nonfood, nonfeed purposes. The sole exception is the 200 million pounds of linseed oil extracted from flaxseed here each year. Since it is inedible, all the production goes for industrial purposes.

But the price and availability of petroleum and foreign oilseeds can change in a hurry, and there is every reason to believe that industrial demand for chemicals from U.S.-produced fats and oils, many of which have properties missing in petroleum, will increase in the years ahead. To this end, the Northern regional laboratory has devoted a substantial share of its resources over the years to finding new industrial uses for soybean, linseed, and other agricultural oils. Many of the products NRRC and other regional researchers have developed since 1940 are already being manufactured today.



In New Orleans, a chemist experiments with a new method of modifying cottonseed oil for industrial use.

During the 1980's, for example, vegetable oils, including 200 million pounds of soybean oil, contributed about 90 percent of the oils used in fabric softeners, 45 percent of the oils in surfactants and 40 percent in various coatings, 20 percent of the oils in synthetic lubricants; 15 percent in plastics additives, and 10 percent in chemicals used in agriculture. Small amounts were also used in making adhesives and in engineering thermoplastics. New processes for converting vegetable oils into industrial products seem likely to increase the use of surplus soybean oil still more during the 1990's. (See "Focus on the Future," p. 147, for some recent innovations.)

Epoxidized oils. During World War II, a team of scientists at the Eastern laboratory found a way to insert oxygen atoms into carbon-hydrogen chains of animal fats in a process called epoxidation. In the process, they helped found a new industry. Epoxidized oils, when used as plasticizers, blend well with commonly used resins. They also eliminate the need for poisonous salts of lead, barium, or cadmium in vinyl plastics, which turn the plastics cloudy or opaque. The epoxidized esters developed at Wyndmoor made possible the manufacture of flexible vinyl plastics.

Before the ERRC research, vinyl had been unstable and inflexible. It turned brittle, especially in direct sunlight. The stable and bendable new plastics could be used for scores of new products, including upholstery and floor coverings, and their manufacture soon expanded into a billion-dollar industry. Soybeans, however, and not animal fats, supply some 75 percent of the 50,000 tons of epoxidized oil now used annually for this purpose.

Polyamide resins from dimer acids. Research begun at the Northern lab in the 1940's led to commercial production and use of polyamide resins prepared from dimer acids. (Dimers are molecules containing identical pairs of simpler molecules.) The dimer acids were derived from soybean and other vegetable oils. For a time during the war, an NRRC resin was manufactured and marketed by two companies under the trade name Norelac, from the words "Northern Regional Lacquer." It was a hard, transparent, thermoplastic resin useful in lacquers and adhesives. Today polyamide resins are used as hot-melt adhesives for shoe soles, book bindings, solders to close seams in cans, and packaging. The widely used 2-tube glues containing epoxy resins and polyamide curing agents also use polyamides developed from the NRRC research. Other uses include moisture-proof coatings, paints for porous surfaces like concrete and cinder blocks, and special-purpose inks. U.S. production of dimer acids today totals about 330,000 tons per year; over half of this is used for polyamides.

Caulking and many other nonfood products are manufactured today using vegetable oil derivatives instead of petroleum.

Cyclic fatty acids. So-called soybean soapstock consists of soy fatty acids that occur as a byproduct of making edible soybean oil. In the mid-1960's, NRRC scientists investigated the production of cyclic fatty acids from the linolenic acid in soybean soapstock and linseed oil. In time, research yielded five kinds of cyclic acids, each with special characteristics of possible interest to industry. One acid, for example, is nearly as effective as erucamide as an antiblock agent to prevent sheets of polyethylene film from sticking together. Another acid can be made into nontoxic alcohols for use in cosmetics. Many promising applications of cyclic acids have yet to be realized.

Nylon 9. In the late 1960's, chemists in Peoria converted soybean or linseed oil derivatives into a versatile new raw material. Working under a USDA contract, a Minneapolis firm developed several ways to use the new material to produce a variety of industrial products. One was nylon 9, a tough plastic especially suited for use in electrical insulation and gears, bearings, cams, and similar parts.

Sucrose partial esters. New sweeteners and changes in U.S. demand made sucrose, or cane or beet sugar, into an inexpensive surplus crop in the 1960's. Starting in 1969, chemists at the New Orleans lab chemically modified sucrose with fatty acids to produce new compounds called sucrose partial esters. For a time, the Food and Drug Administration declined to permit their use in U.S. foodstuffs, and after the processes were patented, the esters were used chiefly in Japan. Today FDA allows their use in this country, and they are now being incorporated in baking and biscuit mixes, baked goods, substitute dairy products, frozen dairy desserts, and whipped milk products. A highly publicized fat substitute was developed from ARS research on sucrose partial esters.

ERRC chemists have developed a group of multipurpose chemicals called isopropenyl esters from fatty acids. They can be used to make paper and cotton repel water, to coat glass to reduce breakage in bottling lines, and in other applications where they have proven superiority to chemicals now in use. The process for making one of the most promising of these chemicals—IPS, or isopropenyl stearate—yields IPS that is 90 percent pure.

High-pressure oil additives. In the mid-1980's, Peoria chemists discovered a new class of compounds that can help make extreme-pressure lubricant additives. New tetrasulfide compounds, derived from vegetable oils or petroleum, are used to treat the lubricants, which may then be used as crankcase or transmission oils, cutting or extruding oils, and continuous steel casting lubricants. The lubricants are effective substitutes for restricted sulfurized sperm whale oil.

New processes for new products. Peoria scientists have developed new, reusable compounds that catalyze processes for making several useful chemical derivatives from fatty acids. These catalysts have opened up new possibilities for use of fatty materials derived from vegetable oils, and many new compounds with commercial potential have already been prepared. Some of them would make good plasticizers for vinyl plastics; others are suited for urethane coatings, rigid urethane foams, coating resins, and lubricants.

Another new approach that may someday pay off uses microorganisms and their enzymes to break down soybean oil into new substances. One bacterium, *Klebsiella pneumoniae*, feeds on glycerol, a common byproduct of animal fat and vegetable oil processing. Through fermentation, the microbe produces a chemical that converts glycerol to acrolein, which is easily converted to acrylic acid, a building block of acrylic plastics, fabrics, and paints. Acrylic acid is made from petroleum and is much in demand. The Peoria process, still being modified, is not yet competitive in price.

Linseed Oil

Linseed oil is the only inedible oil of commercial value still produced in any significant amounts in the United States. More than 80 percent of the flax from which it is extracted is grown in North Dakota, with the rest of the Nation's acreage in South Dakota and Minnesota. The location of the growing area for flax made it the responsibility of the Northern center to find ways to increase the usefulness of linseed oil to industry.

In the 1950's, linseed oil, when used as a drying agent in white paint and enamel, turned yellow when applied in areas not exposed to direct sunlight. It took several years of research at NRRC before the complex chemistry of this after-yellowing was fully understood. Minute amounts of oxidizing chemicals formed in a two-step operation were responsible. Once the mystery was solved, however, small amounts of chemicals were added to the paint to inhibit the yellowing process. An accelerated test was also developed to measure the yellowing properties of oils.

As the 1960's began, the market for linseed oil in exterior paints was starting to slip because of the introduction of petrochemically based synthetic emulsion paints, which were easier to apply, had less odor, and could be cleaned up with water. NRRC and a linseed oil trade association worked together to develop linseed oil emulsion paints, since the oil was known to provide superior protection. Paints were successfully formulated by 1961 that combined the advantages of exterior oil-based coatings with the superior handling and easier application of synthetic emulsion paints. Within 4 years, this research, which cost less than half a million dollars in public funds, had been valued at more than $37 million.

An unusual use for linseed oil was discovered in 1961 by Peoria scientists working with highway researchers. The widespread use of salt to remove snow and ice was causing more and more damage to concrete roads and bridges. One type of damage, called scaling, occurs when thin pieces of concrete break way from the surface. Another type, spalling, occurs when thick pieces break way. Both types of damage, which are accelerated by salt, are most likely to occur when the concrete is new.

Researchers found that a compound consisting of equal volumes of mineral spirits and boiled linseed oil cuts down on spalling. Later, they discovered that spraying an emulsion of linseed oil and water on freshly laid concrete not only acts as a curing compound but subsequently prevents scaling. Within a few years, some 35 State highway departments and many toll and bridge authorities reported using the linseed oil mixtures on roads and bridges. They continue in use today, particularly in northern States where salt is used repeatedly to melt ice during the winter.

New Oilseed Crops

Although the United States is a major producer of edible vegetable oils and animal fats, a substantial tonnage of specialty vegetable oils and waxes used by industry have to be imported. In addition, the United States depends on foreign supplies for at least half its petroleum needs, and billions of pounds of petrochemicals are consumed each year for industrial purposes other than fuel. They include plastics, lubricants, elastomers, surfactants, and a multitude of adhesives, thickeners, coatings, and other industrial chemicals.

The big seeds of the jojoba plant, a native of the Sonoran Desert, yield an oil similar to embargoed sperm whale oil. Unshelled seeds are shown on right.

At one time, before cheaper compounds were derived from coal and petroleum, many of these industrial chemicals were made from vegetable oils. Today, with higher petroleum prices and uncertainties over supply, it may be to industry's advantage to rely less on petrochemicals and more on oils from agricultural crops. With America's negative balance of payments, it also seems prudent to develop specialty crops in the United States that can replace imported vegetable oils.

Since 1957, ARS scientists have conducted a program of new crops research, screening some 8,000 wild plant species from around the world. Most of these plants have been studied by the Northern lab as potential suppliers of industrial oils and fatty acids. In analyzing them, NRRC chemists have discovered some 100 new fatty acids or derived compounds called lipids previously unknown from any source. They also found several likely candidates for new U.S. oilseed crops. If one or more of these new crops could be commercialized, it would not only lessen American dependence on imports of petroleum and such foreign-grown raw materials as coconut oil, but it would also provide U.S. farmers with the opportunity to grow alternative crops not in surplus.

Crambe. Erucic acid, an inedible long-chain fatty acid, is used for many industrial purposes. Oils with high levels of erucic acid are remarkably stable at high temperatures. They have high fire and smoke points, enabling them to withstand the high temperatures required of lubricating and heat transfer oils, while remaining fluid at lower temperatures. At present, the United States uses the equivalent of 40 million pounds of high erucic acid oil annually, most of it imported. Much of this is processed into a product called erucamide, used in making polyolefin films for food storage bags and bread wrappers.

Two good sources of erucic acid are industrial rapeseed, currently a major source of imported oil, and a wild Mediterranean plant called crambe. More than one-third of the seed weight of both plants is oil, of which 50-60 percent is erucic acid. While not yet widely grown in this country, crambe hardly deserves to be called new. It was one of the first oilseed crops studied in the Peoria lab, and 20 years ago, NRRC researchers discovered nylon 1313, produced from a derivative of erucic acid. Nevertheless, today crambe and possibly rapeseed appear to be better bets than ever as important new U.S. crops. In 1990, 2,000 acres of crambe and 15,000 acres of high-erucic acid rapeseed were planted in the United States.

(A low-erucic-acid variety of rapeseed, bred by Canadian researchers, is canola, now grown in both Canada and the United States as a source of edible vegetable oil.)

In 1986, a High Erucic Acid (HEA) Oil Project was begun, with several State universities and the NRRC participating. Its broad goals are to expand commercial use of crambe and industrial rapeseed and to encourage U.S. agriculture to produce more raw materials for industry. So far, research has focused on reducing production costs through increased crambe and rapeseed yields per acre, solving problems associated with processing the seed of both crops, and expanding the market for HEA oils and nylon 1313.

Meadowfoam. Another oilseed plant high in certain long-chain molecules but low in erucic acid was discovered in the early years of plant screening. Meadowfoam, a native of northern California and Oregon, is being grown commercially on a small scale in Oregon, where growers have sold several tons of the oil to Japan and other countries for cosmetics. Meadowfoam oil is expensive, but it has several unique properties. Among other things, it contains virtually no polyunsaturates, which makes it stable to oxidation and temperature. So far, however, no niche has been found for the oil by U.S. industry.

Cuphea. Manufacturers of soap and detergents are heavily dependent upon lauric acid, found in coconut oil and palm kernel oil. About one billion of pounds of these oils has to be imported each year by U.S. industry, since there is no domestic source of lauric acid. In the early 1960's, NRRC researchers discovered that a wild oilseed plant called cuphea was an excellent source of lauric acid and other medium-chain fatty acids. Some cuphea seeds contained a much higher percentage of lauric acid than coconut oil.

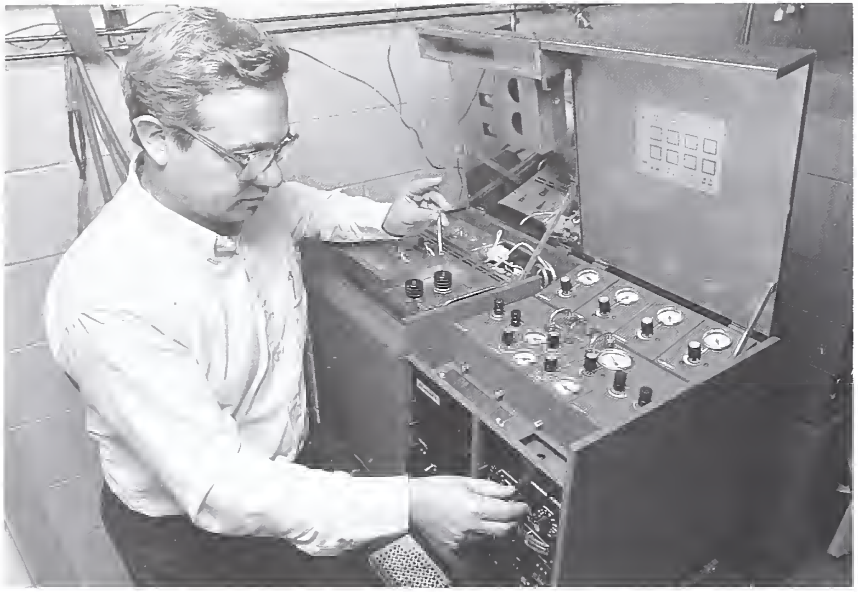
The information lay dormant until the late 1970's, when weather cycles and political instability in several countries exporting coconut oil made many manufacturers uneasy about continued supply. Researchers at the University of Göttingen in West Germany, using NRRC data, began an extensive research program to develop cuphea as a commercial crop. This work was soon expanded to new research in the United States, and today there is close cooperation to learn more about cuphea among industry, university, and government scientists in several countries.

Jojoba. For many years, sperm whale oil was the only commercial source of liquid wax esters for high-performance lubricants, cosmetics, pharmaceuticals, and many other products. Its use was banned by Congress in 1972, however, as part of an international effort to preserve the whale species. Research at the NRRC that began in the 1960's had evaluated oil from a desert plant called jojoba and found it to be a promising replacement for sperm whale oil. Since the ban on whale oil, international interest in jojoba oil has increased rapidly. The unique chemical structure of jojoba was discovered earlier at SRRC.

A native of the Sonoran desert of Mexico, Arizona, and California, jojoba is a bushy plant with seeds about the size of peanuts. Oil from the seeds is nearly 100 percent liquid wax esters; it is similar to sperm whale oil. Commercial plantations as large as 10,000 acres are now producing seed in the United States, Israel, and Latin America, and new plantations are being created in India, Australia, and other countries. Even at present high prices, producers have had no difficulty in marketing their supplies. The high cost of jojoba oil, however, has limited its current use to cosmetics, and industry so far is using synthetic oils to replace sperm whale oil. Recent NRRC research has centered on detoxification of jojoba meal so that it can be fed to cattle.

Lesquerella. The only commercial source of ricinoleic acid, a hydroxy fatty acid, is castor oil, a strategic material. At present, this country has to import about 100 million pounds a year. Screening at the NRRC has turned up several plant species that might be raised as substitutes for the castor plant. One is lesquerella, another desert plant that grows wild in the United States and Mexico. Yields of seed are high and reliable, and prospects for commercial development of the plant look promising to NRRC scientists and others. At present, NRRC is evaluating the oil in comparison with castor oil and developing new products based on its unique composition. This continues a Western lab project begun in the 1960's on lesquerella and

Robert Kleiman, who conducts new crops research at NRRC, uses gas chromatograph to determine fatty acid composition of cuphea seed oil, a product high in lauric acid.



castor, in which WRRC scientists evaluated these oils as components of urethane polymers, among other things.

Vernonia. A native of Africa, *Vernonia galamensis* is a source of epoxy fatty acids, first found to occur naturally in another *Vernonia* species. Production work has been carried out in Africa and Central America by a British investment group, which gave the NRRC enough seed to extract oil for evaluation and product development. The oil proved to be an excellent binder for baked enamel coatings and for other industrial purposes. Current research is aimed at adapting this tropical species to respond to a U.S. day length and climate. *Euphorbia lagascae*, a native of Spain that is another good source of epoxy fatty acids, was also discovered during the NRRC screening. There is currently considerable interest in this plant in Europe.

Domestic Rubber

The United States is the world's largest consumer of rubber, and the search for domestic sources to replace imports of this strategic material continued after the end of World War II. Following the wartime development of synthetic Buna S (see p. 7), chemists created several other synthetic rubbers with special properties. One of these resulted from USDA research.

Soon after the war ended, ERRC chemists were looking for ways to use whey, a surplus byproduct of cheesemaking that was both abundant and inexpensive. They found that lactic acid, obtained by fermenting whey, was a useful starting point for making a class of chemicals called alkyl acrylates. These, in turn, were used to make acrylate polymers. Because the products were rubbery and derived from lactic acid, they were named Lactoprene. Deficiencies in the original product led to further research and an improved product called Lactoprene EV. Commercialized in 1948 by the B.F. Goodrich Company, it was adopted by the automotive industry, where acrylic elastomers are still used for seals that resist oil and high heat. While interest in finding new uses for whey stimulated the original research, the commercial products used today are all derived from petroleum.

Another contribution to synthetic rubber production was made after the war by scientists at the Southern laboratory, who improved the process by substituting a chemical prepared from citrus peel and pine trees for an initiator made from petroleum. The SRRC improvement was quickly adopted by the industry.

In recent years, the search for alternative sources of rubber has begun anew. Congress has made it a matter of national policy that the United States should seek independence from foreign supplies of rubber. First in the Native Latex Act, passed in 1978, and again in the 1984 Critical Agricultural Materials Act, Congress called for development of "economically feasible means" for growing guayule and other "hydrocarbon-containing plants for the production of critical agricultural materials."

The United States cannot rely on synthetic rubber alone. Natural rubber is more elastic, more resilient, and more resistant to heat buildup than synthetics. Also, natural rubber is a renewable resource, unlike synthetics made from petroleum. At present, the United States each year imports some 800,000 tons of natural rubber worth about $500 million. It is indispensable for airplane tires, surgical gloves and dozens of other products. Automobile tires are typically made of synthetic rubber blended with natural rubber.

The new Government policy statements reactivated research by ARS on alternative sources of natural rubber—and on guayule in particular. An ARS chemist in 1978 found that spraying guayule with bioregulators about 3 weeks before harvest causes young plants to produce 2 to 6 times the normal yields of rubber. The ARS scientist said his process would not only increase yields 30 to 35 percent but would also reduce the growing time by a year or two. The bioregulators used are trialkylammonium compounds, a group of organic substances.

In another contribution, scientists at the Northern lab in Peoria developed a 1-minute test of guayule for rubber, resin, and moisture content. It replaced slow and tedious methods of analyzing the plant for rubber content. Presently, researchers are evaluating about 3,000 guayule samples a year from 10 research locations.

And at the Western lab, goldenrod is back in the picture. WRRC scientists believe that techniques of modern genetic engineering might be used to overcome its deficiencies. Chief among these are the fact that it doesn't yield enough latex and that the chemical chains in its rubber molecules are short, making for an inferior rubber. Regional researchers think it may be possible to borrow genes for high rubber production from the *Hevea* plant or guayule and to transfer them, via altered DNA in yeast or bacteria, into goldenrod or other fast-growing plants so they can produce premium rubber. Results, say the scientists, are years away, but they may be well worth waiting for.

In 1947, Eleanor Shutt of the Eastern lab worked on an experimental batch of Lactoprene EV, a rubbery product first derived from lactic acid in surplus whey.

Kenaf: New Papermaking Crop

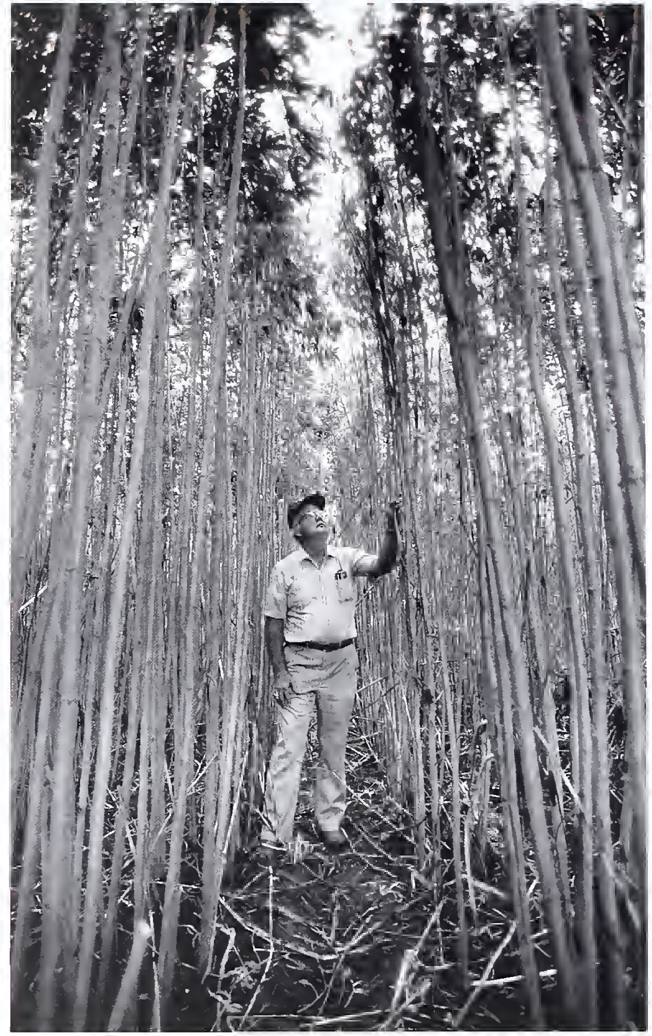
Kenaf, a tall, fast-growing relative of cotton and okra, may be a commercial crop whose time has finally come. That, at least, is the opinion of many scientists, business people, and growers, who are convinced that kenaf will soon provide an abundant domestic source of pulp for paper—and a profitable new crop for farmers.

Kenaf is not a recent discovery. Research on the plant began in 1956, when a team of researchers at the Peoria lab examined some 500 fiber crops, looking for a supplement to wood pulp in the manufacture of paper. Nearly 100 were selected for closer study, and in time, kenaf was singled out as the most promising candidate. Engineers explored the pulping characteristics of the crop and the subsequent strength of the paper, and researchers looked at ways to grow, harvest, and store it. In the mid-1970's, a Peoria chemist developed ways to process kenaf pulp for newsprint.

Product tests followed. *The Peoria Journal-Star* made a successful press run on kenaf newsprint in 1977, and several other daily papers printed editions on kenaf paper later that year. Then, in 1978, NRRC research on kenaf was stopped to allow private industry time to develop the crop further. There was disappointingly little action, however, and since 1986, a federally funded Kenaf Demonstration Project has worked to spur adoption of the crop by the paper industry. A successful kenaf production program would improve this country's trade balance, since at present, we have to import about $4 billion worth of newsprint annually.

Today, through cooperative agreements with several private firms, it looks as if kenaf will finally make the leap from laboratory to industry. In 1988, a Chicago research and development magazine selected the NRRC-developed process for making newsprint from kenaf as one of the 100 most significant technologies of the year. Now, in rural Texas, a cornerstone has been laid for the first commercial newsprint plant to use kenaf, and research is under way at other ARS locations to evaluate the tender tops of kenaf, which are not useful for making paper, as a forage crop for cattle and sheep.

According to ARS research agronomists, kenaf can be grown as an annual crop under a wide range of conditions all over the South and Southwest, and its tops have potential as a supplement in alfalfa-based pellet feed. Further, Peoria scientists have demonstrated that the papermaking qualities of kenaf are not limited to newsprint; they insist that it can make quality papers as well. Finally, from all indications, growing kenaf should provide farmers with a healthy net return.



A stand of kenaf, a fast-growing fibrous plant with the potential to supplement paper pulp from wood, is grown on a farm in the Rio Grande Valley of Texas.

Food Safety

Responsibility for the continuing safety of America's food supply is shared widely among farmers and ranchers, food handlers and processors, private laboratories, and Federal, State, and local agencies. Food safety is also a responsibility of people who prepare meals in the home, in restaurants, and in institutions. It has long been an objective of much of the research conducted by the Agricultural Research Service, and chemists, food technologists, and microbiologists at the regional centers carry out some of the most significant food safety investigations in the country. Their areas of concern include mycotoxins, including aflatoxin; plant toxins; salmonellosis, botulism, and other types of food poisoning; and chemical residues in food, including pesticides and antibiotics.

Aflatoxin. Of all the naturally occurring toxins caused by fungi, the most dangerous is aflatoxin, the name of a group of closely related toxins. They first came to world attention in 1960, when a mysterious "Turkey X Disease" in England killed 120,000 turkeys and other poultry. Cause of the deaths was traced to contaminated peanut meal from Brazil, which was found to contain a potent toxin resulting from the growth of certain molds on crops. The substance was given the name *aflatoxin*. Since that time, researchers in the United States and several other countries have learned a great deal about this toxin and have shown that it is a carcinogen in Fisher rats, ducks, rainbow trout, and other animals in the laboratory. It is also suspect as a human carcinogen. Tolerances of the toxins in foods have been the subject of intense regulatory debate. For many years, a limit of 20 parts per billion set by the U.S. Food and Drug Administration for all commodities except milk was recognized worldwide. Many countries today, however, are imposing even lower limits in foods for human consumption.

Scientists now know that aflatoxins are a product of either of two soil fungi, *Aspergillus flavus* and *Aspergillus parasiticus*. Aflatoxin can contaminate U.S. crops of corn, cottonseed, peanuts, and tree nuts. At first believed to develop only in stored grain and oilseeds or in dead or dying plants in the field, it was soon discovered in developing seed crops as well. Aflatoxin contamination of these crops has resulted in serious losses to growers, food handlers, and processors, particularly in hot, dry crop years, when the mold flourishes after plants are weakened by stress.

Scientists at three ARS regional laboratories have made important contributions for nearly three decades to the world's knowledge of aflatoxin, and research continues today at the Northern and Southern centers. The first comprehensive study on the effects of feeding aflatoxin to livestock and poultry was published in 1971 by a Western lab scientist in cooperation with researchers in New Orleans and Peoria and the University of California. The team established the levels of aflatoxin required to produce recognizable growth effects in swine, beef, and dairy cattle and in broilers and laying hens. The effects on animals of ingesting aflatoxin in feeds may be acute, causing sudden death, or prolonged, resulting in poor weight gains, reduced productivity, and suppression of immunity to disease.

Other ARS scientists conducted the first studies documenting that aflatoxin contaminates corn, particularly in the South. Researchers developed rapid screening tests to detect aflatoxin in corn and found, for example, that corn kernels contaminated with aflatoxin fluoresce with a telltale greenish-yellow glow when exposed to ultraviolet light. This test, known as BGY, proved simple, economical, and fast to perform and could be used for screening corn on the farm and at grain elevators. More than 3,000 crystalline and liquid standards for determining aflatoxin levels were distributed by Peoria researchers to other investigators.

In New Orleans, several significant improvements were made in methodology to detect aflatoxin in cottonseed. These methods first cut analysis time from 4 days to 3 hours. Further research led to even faster quantitative assays, and a chemical means was found to enhance the fluorescence of the already highly fluorescent aflatoxin and to increase the sensitivity of the detection method. The Peoria lab conducted the validation studies that resulted in the analytical method for determining aflatoxin in corn being accepted by the Association of Official

Microbiologists at the regional centers carry out some of the most significant food safety investigations in the country.

Analytical Chemists (AOAC). Other sensitive analytical methods were developed at this laboratory, including techniques for detecting and measuring aflatoxins in milk and in animal tissue. Researchers at the Peoria center were also instrumental in the evaluation and subsequent development of commercial immunochemical test kits for aflatoxins. These kits are widely used today by researchers, grain dealers, and USDA and FDA regulatory agencies.

Once the contamination of grains and oilseeds was recognized, scientists searched for ways to detoxify animal feedstuffs. At the Western and Southern labs, researchers received a patent in 1969 for the ammoniation process for detoxification of aflatoxin. Southern lab scientists found that treating cottonseed meals with gaseous ammonia under heat and pressure for less than an hour of contact time reduced aflatoxin by from 99 to 100 percent without harming the meal for animal feed. A related process, developed by Peoria scientists, detoxified aflatoxin in whole corn under ambient pressure. Neither the high-pressure ammoniation process developed at SRRC for feed meals nor the ambient-pressure process developed at NRRC for detoxifying corn has ever received the needed approval from the Food and Drug Administration. They have been approved, however, in several States.

In Peoria, scientists subsequently developed a trickle ammonia process, an on-farm method that allowed the drying of high-moisture grain with unheated air. Periodic treatment with anhydrous ammonia, fed to the wet corn through an ordinary garden hose, retarded the growth of molds while the corn was slowly dried. Use of unheated air saved fuel. This process did receive Federal approval from the Environmental Protection Agency.

Western lab scientists began in the early 1970's to help the California tree nut industry detect and remove aflatoxin. Among other things, WRRC researchers found that contaminated almonds fluoresce with a characteristic purple color under ultraviolet light. They developed reliable sampling procedures and advised the industry that aflatoxin was associated with damaged nutmeats, which could be removed during processing. WRRC findings enabled processors and growers to improve their processing techniques, resulting in an acceptable product.

Regional researchers have learned more about aflatoxin every year, searching for some means to control the molds in the field or to prevent *Aspergillus* from manufacturing the toxin. They discovered how the fungi survive in field soils in the form of hardened resistant structures called sclerotia. They have demonstrated that germinated sclerotia at the surface of the soil may be the primary source of mold infecting a corn crop. They have learned how soil-dwelling insects commonly known as sap beetles play a role in spreading the fungus by carrying it from the soil to the ear of corn. They also found that the beetles were attracted mostly to ears damaged by the corn earworm. Understanding how the fungus is spread may help reduce its prevalence by encouraging better management of crop residues in the soil.

Meanwhile, Southern lab scientists in 1986 discovered two enzymes in *Aspergillus* that are essential to production of aflatoxin. They are trying now to identify the gene or genes responsible for making at least one of these enzymes, hoping to remove or alter them through genetic engineering so that the fungi will be unable to produce aflatoxin. The capability to identify and thus assay these genes is also important to ensure the safety of naturally occurring non-aflatoxin-producing strains of *A. flavus* or *parasiticus* that could be used for biocontrol.

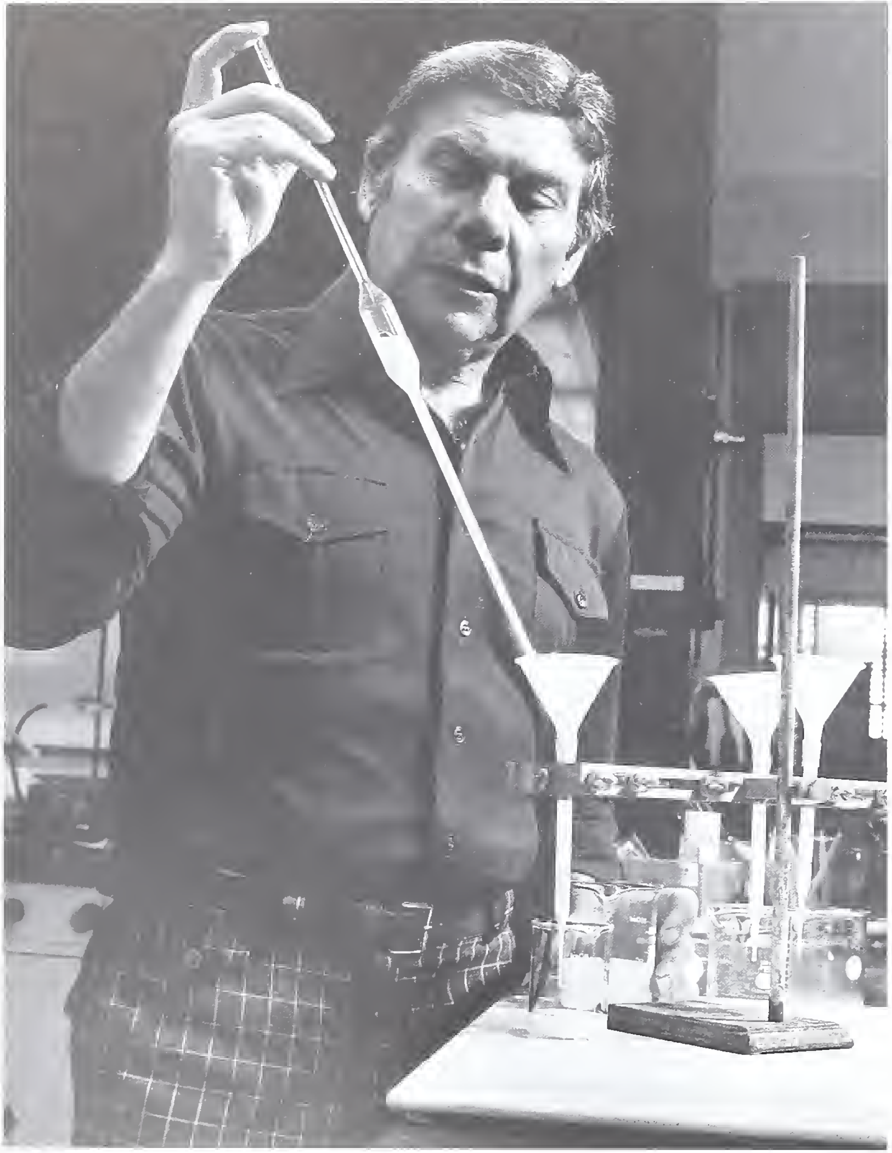
Other mycotoxins. Unfortunately, aflatoxin is not the only dangerous toxin produced by molds. Peoria scientists have studied several others, including mycotoxins produced by *Fusarium* molds, long known to be responsible for many types of plant diseases. Recent research has focused on how and why *Fusarium* makes certain types of poisons called trichothecene toxins. Also under study are the chemicals that a plant produces to defend itself when attacked by *Fusarium* and the chemical combat that results between the mold and the plant.

Work with *Fusarium* has demonstrated that the manufacture of mycotoxins is an extremely complex process that can be understood only after long and ingenious laboratory study. To produce one toxin, labeled T-2, the fungus carries out 13 or 14

An SRRC researcher examines a mold transferred from a corn kernel under ultraviolet light, looking for characteristic fluorescence associated with aflatoxin.

Magnified view of kernel of corn infected with Aspergillus flavus, *a fungus that produces aflatoxin.*

In Peoria, microbiologist Donald T. Wicklow transfers sap beetles from overwintered corn to petri dishes containing a fungal growth medium. Also called picnic beetles, the insects carry Aspergillus *fungi from the soil to corn ears.*



Chemist Daniel P. Schwartz tests milk for traces of the antibiotic chloramphenicol (CAP) in an inexpensive yet sensitive procedure developed by his group at ERRC. Use of the drug in dairy cattle and meat animals is illegal.

separate steps, of which the sequence of all but 4 has been determined by NRRC researchers. It is necessary for scientists to know exactly how toxins are produced before they can develop effective ways to prevent them.

In 1988, an important new toxin called fumonisin was reported. The toxin is deadly to horses and swine and is a potential carcinogen in humans. Again Peoria researchers promptly carried out needed toxin research. Within months of the first report, they became the first scientists in North America to isolate the new toxin and, what is even more important, they were able to develop a sensitive analytical method to detect fumonisin in corn and corn products. Unusually large numbers of horse deaths and swine illness occurred at several places in the Midwest as the 1989 corn crop was used. Fumonisin concentrations in corn screenings linked to the livestock deaths were measured using the Peoria method.

Botulism. The food poisoning most often fatal to human beings is botulism. Fortunately, because it has been recognized for many years and effective controls have been developed for food processing and preparation, its incidence today is low. Botulism is caused by a toxin formed in the absence of oxygen by *Clostridium botulinum*, a bacterium found in the soil. Long the bane of home canners, it has been found all too often in jars of low-acid foods like green beans that have undergone insufficient heat processing. Several cases in New York City were once traced to a single jar of mushrooms, preserved by a restaurant owner. Symptoms of botulism are weakness, headache, disturbed vision, and paralysis. The only treatment is an antitoxin that is available from health departments.

Canned tomatoes were long considered safe from botulism by virtue of their high acidity, and at home and commercially, they were processed only briefly. In the 1970's, however, several cases of botulism were traced by health officials to home canning of low-acid tomatoes, varieties widely available to home gardeners. As a result, Eastern center scientists identified several tomato varieties with an acid content low enough to constitute a hazard with routine canning. They also found that many presumably safe varieties of tomatoes were risky for canning if overripe or decayed.

The result was publication of a brand new set of procedures for safe home canning of tomatoes and tomato sauces, juices, and blends with other vegetables. One important ERRC recommendation was to increase the acidity of tomatoes with citric acid or lemon juice before canning to prevent the growth of the botulism bacterium. The new guidelines were disseminated by the media and extension workers. A few years later, a computerized data bank at the Eastern lab contained 450 safe canning recipes, mostly for tomato-based products.

One important ERRC recommendation was to increase the acidity of tomatoes with citric acid or lemon juice before canning to prevent the growth of the botulism bacterium.

Botulism struck again in the United States and the USSR in canned tomato juice. In tests by mystified health officials, the products appeared to be acid enough to prevent formation of the poison. Again, ERRC scientists found the answer. The *botulinum* organism may thrive, even in a high acid product, they found, if certain molds are growing on the surface. The molds decrease the acidity of the tomato juice near the top, at the same time using up the oxygen that prevents the botulism from forming. Samples analyzed by local officials had been shaken, disguising the low acidity of the topmost layer of juice by mixing it with the rest of the juice in the can. Careful handling at the Philadelphia lab led to discovery of the hiding place for the toxin and to recommended procedures for preventing the problem.

A third discovery about botulism at the ERRC has since been widely disseminated by pediatricians and nutritionists. Infant botulism is the result of a *botulinum* infection of the intestinal tract in babies less than a year old. The source of the microorganism in several cases, researchers found, was honey. The most likely explanation, according to ERRC scientists, is that bees sometimes pick up spores of *C. botulinum* from contaminated water and carry them to the hive, where they adulterate the honey. Normal processing and packaging of the honey does not kill the spores. The studies resulted in a recommendation that honey not be fed to infants under 1 year in age. Children older than that do not contract the ailment.

Salmonella, *Listeria*, etc. Research to protect food from other types of bacterial food poisoning has been a major project at the ERRC since the mid-1970's. One of the first concerns was the presence of *Salmonella* bacteria in poultry products—still a problem today. ERRC scientists have come up with equations for poultry processors that enable them to predict the growth of *Salmonella* at various levels of saltiness, acidity, temperature, and oxygen. The model systems have been applied to the safe processing of poultry frankfurters and other products.
This work has recently been refined and expanded in a computer program that predicts the growth in commercially processed foods of several food-poisoning pathogens. Functioning as a kind of early warning system for processors, the program can reduce by 75 percent the number of tests for food poisoning bacteria now performed by the food industry.

To predict the growth rate of various harmful bacteria, ERRC scientists know that five key pieces of information are necessary: levels of oxygen, acidity, salt, storage temperature, and sodium nitrite concentration. Using information about these five factors, which interact to control the growth of microorganisms, ERRC scientists developed equations that enable them to predict the growth of pathogens. They first predicted growth patterns in foods of two bacteria that can be found in meat and dairy products, *Salmonella* and *Listeria*. Salmonellosis is estimated to cost nearly $1 billion a year in medical expenses; listeriosis, about $250 million. The growth curves in the computer program for *Salmonella* are based on research conducted by a team of British scientists; the *Listeria* curves are the result of 700 experiments performed at the Eastern center.

The work has recently been refined and expanded in a computer program that predicts the growth in commercially processed foods of several food-poisoning pathogens that can occur in meat, dairy products, and seafood. These include *Shigella, Aeromonas, Staphylococcus, Escherichia coli 0157:H7,* and *Bacillus cereus.* So far, some 300 companies have expressed an interest in using the computer model. *Salmonella* in fresh poultry meat can be sharply reduced or eliminated by treatment with ionizing radiation at pasteurizing doses that do not lower the nutritive value of the meat in any appreciable way. The process has been approved by the Food and Drug Administration and USDA's Food Safety and Inspection Service, making it permissible for industry to use ionizing radiation to provide fresh poultry to the consumer that is free of *Salmonella.*

A different approach to reducing the incidence of food poisoning is presently being sought by another ERRC researcher. It is a bacterial "hit man" that kills *Salmonella* and other food pathogens. Three species of the rod-shaped *Bdellovibrio,* all of them parasitic bacteria, are common inhabitants of soil and water. Harmless to people, they feed on Gram-negative bacteria, a broad class of microorganisms that includes *Salmonella.* A *Bdellovibrio* bacterium can kill a *Salmonella* bacterium in half an hour. Hopefully, the bacterium can be sprayed on meat, eggs, and milk during processing and packaging to help control food-poisoning pathogens. If *Salmonella* started growing in the food, the *Bdellovibrio* could gobble them up. "Even if the idea works," comments a scientist, "it would be no substitute for adequate cooking and refrigeration to prevent food poisoning. It would simply provide extra insurance for the consumer."

In other food safety research, improved tests were developed at ERRC for detecting an agent of food poisoning, *Yersinnia enterocolitica,* that can grow at temperatures as low as 32°F. A purple dye binds to this bacterium but not to harmless ones, making it easier for industry and regulatory agencies to pinpoint virulent strains.

In another ERRC study, this time with *Listeria,* researchers found that once *L. monocytogenes* has contaminated a food processing plant, it can persist for long periods if the temperature is low enough and the bacteria are suspended in various foods. A more reassuring finding was that current methods of processing frankfurters can prevent growth of *Listeria.* Researchers demonstrated that a standard frankfurter process carried out in the ERRC smokehouse was sufficient to inactivate the *Listeria* likely to be encountered in the product prior to cooking.

Chemical Residues. The USDA's responsibility for ensuring the safety of meat, poultry, and eggs requires analysis of more than 100,000 samples a year for residues of drugs and other chemicals. To assist in this task, ERRC researchers have devised new ways to speed handling of analyses and to screen samples for residues on the farm or in the plant. A robot, for example, performs a procedure that detects half a dozen drugs at once, automatically helping check for residues at levels as low as 100 parts per billion. In another instance, a simple, low-cost analysis signals analysts with a color change when a test chemical is exposed to meat extracts, milk, or urine containing certain chemical residues, including antibiotics. And a commercial test for residues, based on immuno-chemistry, was modified by ERRC chemists so that a farm or dairy worker without specialized technical training can carry it out. In this way, farmers and plant operators can make sure their products are residue-free.

The USDA's responsibility for ensuring the safety of meat, poultry, and eggs requires analysis of more than 100,000 samples a year for residues of drugs and other chemicals.

Similar investigations are conducted at the Western center, where there is a search for better ways to detect residues of a class of chemicals used as fungicides and to kill intestinal parasites in meat animals. Current methods of analysis are slow, requiring a check for one chemical at a time, and they are inconvenient for field use. WRRC scientists are developing antibodies that will react with whole groups of these chemicals in an effort to develop tests that will screen for several residues at a time.

In a related area of concern with chemicals, ERRC played a major role in nitrite-nitrosamine research. (See chapter on "Meat and Meat Products," p. 75.) Researchers helped avert a ban of both nitrite and bacon advocated by consumer groups and changed the way bacon is produced by the meat processing industry. ERRC scientists developed analytical methods, elucidated the chemistry involved, studied processing techniques that affected the formation of nitrosamines, and developed means for their reduction in bacon. They also helped change relevant Federal regulations.

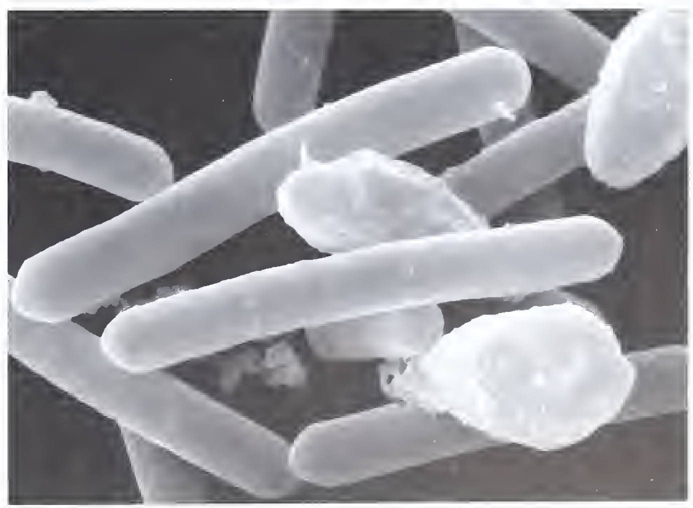
Radioactive Fallout. Concern over the effects on U.S. food supplies of radioactive fallout reached a peak in the 1950's, with atomic testing in the United States and the Soviet Union. In the early 1960's, the Northern and Eastern centers, in cooperation with other Federal agencies, developed ways to reduce or remove radioactivity in wheat and milk. Peoria scientists found that strontium-90 can be reduced to safe levels in wheat and wheat products by washing the wheat with dilute solutions of phosphoric or citric acid. ERRC scientists were able to remove radioactive strontium from milk by passing cold raw whole milk through a column containing a strong acid ion-exchange resin. The flavor of the resin-treated milk was satisfactory. A pilot plant was subsequently built that removed both the radiostrontium and radioiodine-131. Both the NRRC and ERRC research assumed new importance following atomic plant disasters at Three-Mile Island and Chernobyl.

Natural Toxins. When grown under adverse conditions, some varieties of potatoes contain naturally occurring compounds called glycoalkaloids that are toxic to humans. In the early 1970's, to cite one instance, potato breeders developed a new variety with excellent pest resistance—always an important goal. Shortly before it was released, several graduate students became ill after eating some of the experimental potatoes, which had been grown in a greenhouse where they worked. The variety, needless to say, was never released.

The incident underscored the need for monitoring toxic compounds in the ever-growing number of new potato varieties. ERRC scientists developed several ways to analyze potatoes for content of glycoalkaloids so that breeders can find out prior to their release if their varieties would be toxic to people as well as to insect pests and nematodes. Fortunately, the research has identified several nontoxic potato species with good resistance to such problem pests as the Colorado potato beetle. With increasing restraints on the use of pesticides, built-in resistance is essential to maintain a satisfactory level of potato production.

So-called anti-nutritional factors that block or inhibit trypsin, an enzyme the body needs to digest protein, have been isolated by Northern center researchers from raw and heat-processed soy flours. Simple, inexpensive techniques have been developed at

James L. Smith, ERRC microbiologist, checks a growth medium for evidence of bacteria that can cause food poisoning. Using the right medium, says Smith, is essential to getting an accurate bacterial count.



Magnified food spoilage microbe Clostridium botulinum *produces a toxin in the absence of oxygen that is often fatal to humans. The sac-like dormant spores can survive conditions that are lethal for the rod-shaped cells.*

NRRC for inactivating these inhibitors, but food processors first need to know if they are present before they can take steps to eliminate them. In 1989, Western center researchers developed tests that make use of monoclonal antibodies to enable processors to check their products for traces of enzyme inhibitors. The tests are also useful to breeders seeking crop varieties low in both types of protease inhibitors. There is also interest by medical researchers in the inhibitors found in soybeans as possible cancer-fighters.

Food Adulterants. The addition of most adulterants to food, if the consumer is not informed of their presence, is not unsafe as much as it is unethical. It is also likely to be illegal. The addition of vegetable proteins like soybean extenders to hamburger, for example, may even improve its nutritional qualities, but customers nevertheless have a right to know exactly what they are getting for their money. Regulations say that additives in food must conform to labeling requirements and meet product standards.

ERRC scientists have devised several chemical and immunological tests for identifying the source and amount of protein in sausages and frankfurters. This provides USDA's Food Safety and Inspection Service, as well as State agencies, with new tools for monitoring food products for the presence of undeclared adulterants. Particularly ingenious methods of analysis were invented at ERRC to detect adulteration of honey and orange and apple juice with enzyme-converted cane and corn syrups. By the mid-1970's, significant amounts of these syrups were being added illegally to juice and honey, and traditional analytical methods were inadequate to spot them. ERRC scientists found that the two juices and honey contained characteristic ratios of two carbon isotopes. The adulterants contained higher ratios and could be detected in mixtures of juice and syrups. A second method of analysis based on chemical ratios soon followed, and both are now officially sanctioned all over the world for monitoring for adulterants.

Human Health and Medicine

There were perhaps no more important discoveries in the regional laboratories than those in Peoria that led during World War II to the mass production of penicillin. (See "Penicillin and the War Years," p. 5.) The work not only helped launch the vast antibiotic industry, but the deep vat fermentation techniques used also formed the basis for future fermentation processes in many other areas. But the regional centers have made other significant contributions to human health and medicine, some as a consequence of research on crops and other plants of economic interest. Other projects have been undertaken to utilize the vast ARS collection of microorganisms located at the NRRC. Discoveries have been made by researchers in all four laboratories about steroids and hormones, new drugs from plants, and allergic and toxic reactions to food and fiber. Much of this research was later carried forward by medical research agencies, universities, and pharmaceutical companies.

After discovery of streptomycin in 1943 at Rutgers University by Selman Waksman, there was accelerated research to discover other antibiotics from among a group of soil microorganisms known as *actinomycetes*. Pharmaceutical company laboratories found chloromycetin, aureomycin, and terramycin. Researchers at several locations, including the ARS center in Peoria, discovered polymyxin, an antibiotic, in 1947, and NRRC scientists found a way to increase production of the antibiotic, as they had earlier with penicillin. In 1948, Waksman discovered neomycin, and in 1950, an NRRC team found a new form of streptomycin, produced by a different actinomycete.

An important commercial success stemmed from research at the Eastern center on rutin, a drug found by the University of Pennsylvania Medical School to help prevent hemorrhaging in small blood vessels as a result of high blood pressure. Rutin was extracted from flue-cured tobacco for the university trials, but tobacco was too expensive a source. An ERRC research team found a much better supply in green buckwheat and over several years developed a way to extract and purify the drug from buckwheat for therapeutic use. The process was adopted by several companies and was used until a shift occurred in the 1960's from buckwheat to imported eucalyptus leaf as a source of rutin.

In 1948, the steroid cortisone was found to relieve rheumatoid arthritis, and there was an urgent demand for precursors from which to produce cortisone and other steroids. A worldwide search was conducted for plants containing these precursors, and plants were screened by the ERRC and other USDA groups in cooperation with the National Institutes of Health.

A key compound in the synthesis of cortisone is progesterone, another steroid hormone, which in turn can be made from compounds called sapogenins, found in certain plants. One of these compounds, diosgenin, was of particular interest. Some 6,600 plant species were collected and screened for diosgenin in the 1950's, using assay techniques developed by Eastern lab scientists. Highest yields of the compound were found in the Mexican yam, in the plant genus *Dioscorea*. Within a few years, some 70 percent of the steroids produced in the United States were made from the diosgenin in these tubers, which grow wild in Mexico, Guatemala, and South Africa.

In carrying out the search, ERRC scientists learned a great deal about steroids and about processes for converting plant sapogenins to cortisone. The contributions of Wyndmoor scientists were documented in scores of publications and patents, and four new sapogenins were discovered, characterized, and named. In addition, the work identified many new plant sources of steroids that could be converted to cortisone.

In the late 1950's, scientists at the Western lab developed tests to identify the materials in castorbean meal that caused allergic reactions in many people. Researchers not only found the allergens, but in the process they exonerated one chemical that had been blamed unfairly for the allergies. They then developed a way to inactivate one of the most potent allergens in castorbean meal.

In Peoria, chemist Richard Powell examines new accessions of plant seeds from all over the world in a systematic search for new sources of human medicines.

More than a decade later, WRRC researchers carried out basic research to identify the toxic substances in gliadin proteins in wheat. These substances are toxic only to about 1 in every 2,000 people in the United States (and as many as 1 in 300 in Ireland). The condition, known as celiac disease, is thought to be hereditary. Eventual aim of the WRRC research is to use genetic manipulation to remove the toxic gliadins from wheat.

Ellen J. L. Lew, a Western lab chemist, was part of a team that identified the toxic substances in gliadin proteins in wheat that cause allergic reactions in many people.

During the 1960's, a worldwide plant search began to find new drugs, including cancer-fighters. By the early 1970's, plant explorers, many of them USDA scientists, had collected 20,000 species, and 1,500 of them showed enough promise as drug sources to justify further study. Much of the initial analysis was carried out by NRRC researchers, in cooperation with several universities.

One of the most promising drugs discovered at NRRC was harringtonine, a leukemia inhibitor found in minute amounts in a Japanese plumyew tree, a rare Asian evergreen. Nearly a decade later, Peoria chemists succeeded in synthesizing the drug from another and more plentiful plumyew compound. Studies of the drug continue.

An inhibitor of one type of leukemia was isolated in the 1980's from *Sesbania*, a species of toxic legume that grows on the coastal plains of the South. Popularly known as coffeeweed, the plant's seeds yield a compound named sesbanimide that has demonstrated encouraging antitumor activity in tests with mice. The NRRC research, which was carried out with scientists at

Reducing Cotton Endotoxins

The Southern center has patented a way to reduce levels of natural toxins produced by bacteria on cotton plants. Called endotoxins, the poisons are believed to be a cause of byssinosis, a lung disease found in some cotton textile workers. Workers can inhale the toxin from dust created when cotton travels through various processing steps.

SRRC scientists found that washing cotton in a solution of alcohol and sodium hydroxide, or household lye, after ginning can eliminate as much as 95 percent of endotoxin before it reaches the textile mill. Cotton dust so treated has been tested on animals, which showed no ill effects. Researchers also found that heat can destroy the toxin.

Cornell and Purdue universities, has now moved forward to clinical trials at the National Cancer Institute.

Other promising anticancer drugs found through plant searches include a rare compound discovered in *Trewia nudiflora*, a tree native to tropical areas of India, and taxol, a potent drug discovered by the National Cancer Institute. Unfortunately, the only known source of taxol is the bark of the Pacific yew tree, *Taxus brevifolia*. An extremely slow grower, the Pacific yew is found only in old-growth forests of the Pacific Northwest. Not only is it a rare species, but it takes 10,000 pounds of the bark to produce one pound of taxol for clinical trials. Many conservationists fear that demand for the drug could lead to the tree's extinction.

Responding to the need for increased supplies of taxol, researchers at the Southern laboratory have established plant tissue cultures of *T. brevifolia*, and these cultures have already produced detectable quantities of taxol. The next steps are to identify high-yielding cell lines and to work out a bioprocess for production of the drug. In late 1990, ARS scientists at another location were working on both projects.

Regional drug research has not been limited to chemicals to fight cancer. The Southern lab, for instance, while searching for new food preservatives, found three compounds that show promise in fighting *Staphylococcus* infections resistant to most antibiotics. And the Western lab has succeeded in establishing vigorous cell colonies of a plant called heavenly bamboo that produces berberine, an antimalarial drug. These and similar discoveries underscore the need to preserve the diversity of plant species throughout the world.

At the Eastern center, scientists have worked on ways to curtail production of drugs that are manufactured and sold illegally. They found, for example, that administering a chemical called ethephon to opium poppies releases the plant hormone ethylene, causing opium capsules to fall from the plant prematurely. A problem with this and similar discoveries is that many drugs sold illegally are also produced for legitimate medical purposes.

Discoveries within the last 10 years at two ARS regional laboratories should make it easier for people to eat more fiber and lower their cholesterol.

Fiber and Cholesterol

Discoveries within the last 10 years at two ARS regional laboratories should make it less of a chore for people to eat more fiber and lower their cholesterol. And there is other good news about cholesterol as well.

Following up on years of SRRC research on extraction of rice bran oil, a team of scientists at the Western lab developed a new process to stabilize the bran. Rice bran is high in vitamins, minerals, proteins, and fiber. Rice oil is high in vitamin E, and in tests with animals, it lowered blood cholesterol. Until recently, the oil in untreated bran turned rancid soon after milling, ruining both oil and bran. For this reason, rice bran has been used either as an animal feed or, in tropical countries, as a fertilizer. In an inexpensive new WRRC process, the freshly milled bran is cooked to inactivate the enzymes responsible for oil deterioration. The cooked bran, still containing from 20 to 22 percent rice oil, can be used as a cereal, or, as an alternative, the oil can be removed to produce an excellent salad oil. (See also "Rice," p. 114.)

The U.S. rice industry has committed itself to adopt the WRRC recommendations for processing and storage of bran, and several Third World countries have begun to install the stabilization systems. From 30 to 40 million tons of rice bran containing 6 to 8 million tons of oil are produced annually around the world.

Studies of oats are also under way at the WRRC to investigate further the ability of that cereal grain to lower cholesterol levels. There are also indications that oat fiber may help control diabetes by preventing erratic swings in blood sugar levels. Researchers speculate that it may accomplish this by slowing the rate of carbohydrate absorption in the intestine.

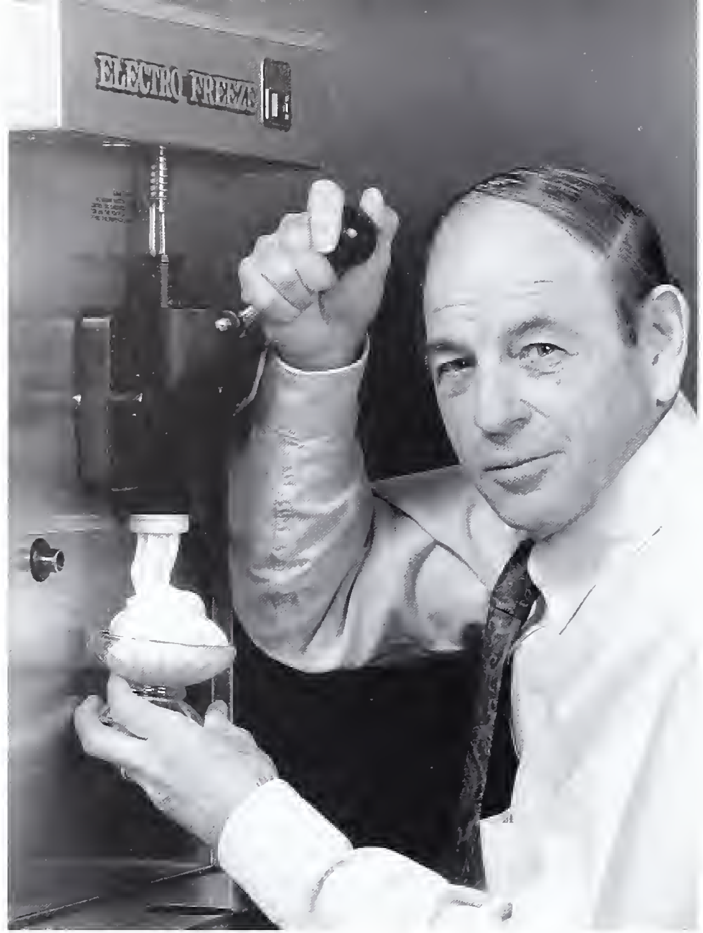
Meanwhile, a chemist at the Northern lab in Peoria has made a low-calorie, cholesterol-fighting fat substitute from soluble oat fiber. He has named it oatrim and used it as an ingredient in an ice cream substitute, among other things. Unlike fat substitutes already on the market, oatrim is a natural fiber made with natural enzymes. It contains beta-glucan, reportedly a contributor to lowering blood cholesterol.

In Peoria, a taste panel rated a frozen vanilla dessert made from oatrim only slightly lower on several characteristics than it did premium ice cream. Several panelists said they preferred the lighter texture of oatrim to the heavy cream taste of the ice cream. A 4-ounce serving of the dessert made with oatrim has 135 calories, less than 1 gram of fat, and 4 milligrams of cholesterol. A similar serving of premium ice cream, says oatrim's inventor, has 298 calories, 22 grams of fat, and 85 milligrams of cholesterol. Several food companies are evaluating production and marketing of the product.

Another Peoria scientist—a biochemist—discovered in 1983 that 12 hours of soaking plant residues in hydrogen peroxide, a hair bleach and household antiseptic, will free the cellulose in the residues from the indigestible lignin. (See "Feeds, Forage, and Fodder," p. 67.) An incredibly complex substance, lignin is the woody natural cement that binds cellulose and prevents its breakdown by enzymes. Released from the lignin, wheat straw, for example, disintegrates into highly absorbent fibers with a pulplike consistency. Similar products are released by treating brans, hulls, stems and stalks, and even corncobs. When first discovered, the process was greeted as an improved source of livestock feed and possibly as a source of industrial materials.

In further experimentation (some of it in his own kitchen), the biochemist found that the "fluffy cellulose" from plant residues can provide a safe, inexpensive source of fiber for human consumption. It contains no metabolic calories and is a flavorless, high-fiber additive that can be baked into bread, cereals, doughnuts, pancakes, and similar foods. One national bakery has already marketed a white bread containing the cellulose, and a rural firm is preparing to manufacture a flour containing fluffy cellulose derived from the outside layer of corncobs.

In research on cholesterol at the Eastern regional laboratory, researchers found that pectins, the substance found in apples that makes jelly gel, may lower blood cholesterol.



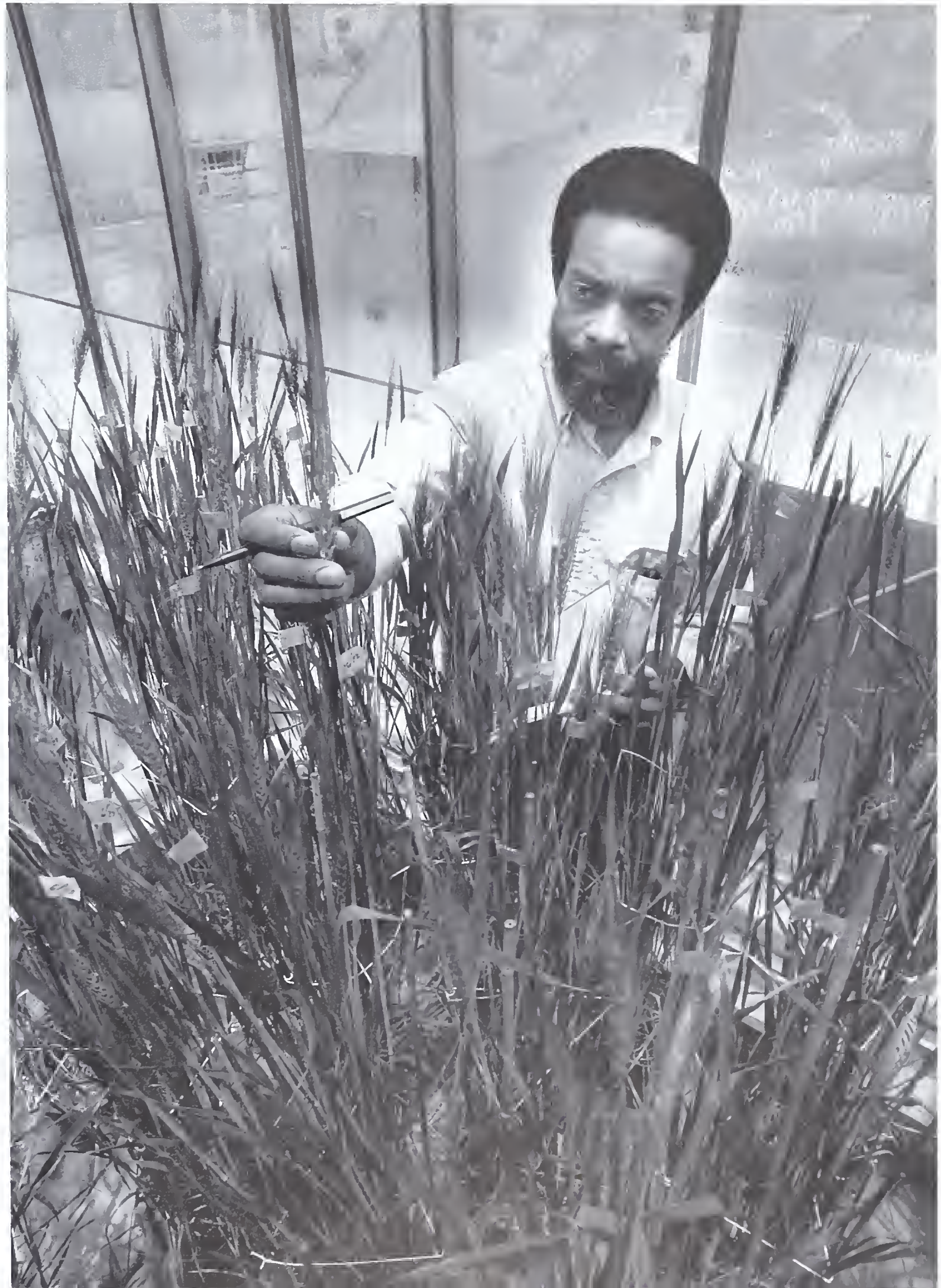
George Inglett, an NRRC chemist, prepares a frozen dessert containing oatrim, a low-calorie fat substitute he developed that may help lower blood cholesterol.

In other research, a Wyndmoor scientist found that the human body's own digestive juices appear to provide a defense against potentially cancer-causing compounds produced from cholesterol during cooking and food processing. When cholesterol comes in contact with oxygen at high temperatures, such as during frying, a small part of it is transformed into compounds called cholesterol oxides. Two of these oxides were found to be carcinogenic in animal experiments. If ingested by human beings, however, gastric juices transform the chemicals into other compounds that are noncarcinogenic. "It appears to be one of our natural defenses," comments the researcher who carried out the experiments.

Wheat, Flour, and Bread

Light bread, leavened bread, bread raised with yeast, is nothing new. It was made in ancient Egypt, in Babylonia, in Greece. In Rome, the Emperor Trajan in 100 A.D. started a school for bakers. Then, as now, it was made from wheat, or from a mixture of wheat and rye. The elastic gluten in wheat is essential for bread to rise. But some things have changed in making bread. For one thing, it is mass-produced today. Brews of yeast, made in vats, are mixed continuously with flour, water, and other ingredients at one end of a machine. At the other end, bread dough is extruded and shaped and cut automatically into loaves. The loaves drop into pans, rise, and are baked at the rate of thousands an hour. Similar high-speed machine operations make cookies and crackers and other baked items.

Another change is what goes into a loaf of bread today. Besides the "enriched bleached bromated wheat flour" listed first on the wrapper of a loaf of cracked wheat bread, there are the following ingredients: water, cracked wheat, high fructose corn syrup, yeast, soybean oil, nonfat milk, salt, whey, calcium sulfate, sodium stearoyl-2-lactylate, and sodium caseinate. The wrapper also explains that wheat flour contains, besides wheat, malted barley flour, niacin, iron, thiamine mononitrate, riboflavin, and potassium bromate.



In his greenhouse at the Western center, chemist Frank Greene checks development of wheat grown for protein studies. The aim is to enhance bread-making qualities.

U.S. Wheat Classes

There are many varieties of spring and winter wheat, but they are grouped into only five official classes, reflecting hardness and color of kernels and planting time.

Hard Red Winter is a major bread wheat that accounts for more than 40 percent of the U.S. wheat crop and wheat exports. It is planted in the fall in the Great Plains.

Hard Red Spring, also an important bread wheat, has the highest protein content. It is spring-seeded in the north central States.

White Wheat is preferred for noodles, flat bread, and other nonleaf bakery items. A low-protein wheat, it is grown in the Palouse, in the Pacific Northwest.

Soft Red Winter is a fall-seeded, high-yielding wheat, grown in the eastern States. Relatively low in protein, it makes flour for cakes, pastries, crackers, and snack foods.

Durum, the hardest U.S. wheat, provides semolina for pasta. Seeded primarily in the spring in the same northern areas as hard red spring, it is also winter-sown in small quantities in the Southwest.

With the exception of soft red winter, each class of wheat has several subclasses, which often grow side-by-side in the same field. The variable properties of these wheats pose difficulties for millers and bakers in producing standardized products. These problems are the subject of continuing research at the Northern and Western regional centers.

WRRC chemist John Bernardin (foreground) studies banding patterns of wheat proteins exposed to various temperatures, while geneticist William Inwood extracts protein from wheat endosperm.

Mass production and the use of additives in baking have created special problems for the baker, miller, and farmer. Even the same classes of wheat can vary significantly in baking qualities, and when these differences are great enough, they can cause havoc in a bread factory. And each new additive in flour or bread can also affect baking qualities. For 50 years, chemists at two regional laboratories—the Northern and Western—as well as at other ARS laboratories including the U.S. Grain Marketing Research Laboratory at Manhattan, Kansas, have been working with all segments of the industry to help them provide consumers with uniform, flavorful, nutritious bread and other wheat products.

Among other things, regional scientists identified and isolated proteins in wheat not previously known to exist. NRRC researchers separated wheat gluten into two fractions—gliaden and glutenin—and they showed that these proteins contain a specific chemical structure, the sulfhydryl group, that affects the mixing properties of flours in forming doughs. They discovered the role of fatlike constituents in flour in controlling the volume of bread and size of cookies. They found that certain water-soluble proteins, known as albumins, are as essential as gluten in producing a good loaf of bread.

A specialized milling technique for fine grinding and air classification of wheat flour provided a new way to adjust the composition of cereal flour. Developed at the Northern lab, it produced fractions higher or lower in protein content than the original flour. The fractions could be used as blending agents for fortifying bread flours and for specialty flours for cakes and cookies.

Over the years, NRRC technologists have baked thousands of loaves of bread to test different wheat flours and to determine the effects of each new additive. As new analytical techniques have become available, more and more detailed information about wheat has been added to the pool of knowledge, to the benefit of wheat breeders, farmers, and industry. In the 1980's, for example, WRRC scientists scanning flour samples with near-infrared wave lengths of light discovered the surprising fact that NIR data correlated very well with the potential

Finding the "Sour" in Sourdough

San Francisco sourdough bread, a heavy, crusty product with a faintly sour taste, was for many years unique to the Bay Area. Made with a starter dough, or mother, local bakers insisted that sourdough bread couldn't be duplicated farther than 50 miles from the center of San Francisco. They didn't know why; it just couldn't.

Researchers at the Western center across the Bay from San Francisco decided in the late 1960's that there had to be a scientific answer to the mystery of sourdough bread. Like most scientists, they didn't like unsolved riddles. One puzzling thing about the bread was its high acetic acid content, which contributed to its sour taste. Yeasts customarily used to make bread rise can't tolerate acetic acid.

Obtaining samples of starter doughs from five local bakeries that were making the bread, a scientist found in all five a bacterium never before discovered. Naming it *Lactobacillus sanfrancisco*, he spent several months and tried 30 different substances before he could find a medium to grow the bacterium. The other thing he found was a yeast, *Saccharomyces exiquus*, that was unusually tolerant of acetic acid. It worked with the bacterium in a symbiotic relationship to produce the bread's unusual flavor, crust, and texture. Comments the scientist: "It was a happy marriage between two noncompetitive bugs."

As a result of the WRRC research, San Francisco-style sourdough bread today can be baked anywhere in the world. And the discovery wasn't all bad news for local bakeries unwilling to share their secrets. Pure cultures of *L. sanfrancisco* are now grown commercially and are commonly used by San Francisco bakers to control the quality of their product.

In subsequent research, ERRC scientists and industry jointly developed a simple new procedure for making the bread, using sour whey and vinegar instead of bacteria as sources of acetic and lactic acids. When the acids are added to a French bread formula in the quantities and proportions found in the traditional product, the resultant bread has a resilient body, robust flavor, coarse structure, and crisp chewy crust comparable to San Francisco sourdough bread. The procedure, according to ERRC, can be adapted to any bakery equipped to make hearth breads and eliminates the need for frequent starter dough transfers and the 20- to 22-hour fermentation period.

volume of loaves of bread. NIR then became yet another standard technique in the wheat scientist's analytical toolbox.

Fifty years of regional research on wheat and wheat flour presents a historian with an embarrassment of riches. A brief selection of research findings during the last 10 years may illustrate the scope, originality, and importance of this scientific work. Americans today, unlike the residents of other developed countries, have reversed a long-time trend and are eating more bread than ever. That fact alone suggests that commercially baked bread and rolls taste better than they once did. Part of the credit for that belongs to the researcher, as it does to the grower, the miller, and the baker.

In Peoria, a chemist reports that with samples as tiny as half a kernel, he can help wheat breeders analyze a type of gluten protein—gliadin—that may provide some of the qualities that bakers want in their flour, including the property of producing uniform loaves of bread with just the right crumb texture.

Despite all that has been learned in the past about wheat, research is accelerating today. In Peoria, a chemist reports that with samples as tiny as half a kernel, he can help wheat breeders analyze a type of gluten protein—gliadin—that may provide some of the qualities that bakers want in their flour, including the property of producing uniform loaves of bread with just the right crumb texture.

"When breeders are building new wheats to resist the latest strain of a disease," says the chemist, "we can check on the proportion of gliadin in kernels from the most promising plants. That can give us an early indication of how the flour will mix and bake." The analysis is carried out with a high-tech procedure called reversed-phase high performance liquid chromatography. "It provides us," the researcher says, "with an incredible amount of information. And it gives it to us in a day instead of in months or years."

At the Western center, scientists have been working with glutenin, the other important protein in wheat gluten. Some scientists speculate that heavy glutenins with high molecular weights add strength and elasticity to bread doughs. Both are considered desirable characteristics by bakers. A team of chemists in Albany is exploring the structure of glutenins of assorted molecular weights, shapes, and sizes. The research could help in the genetic engineering of glutenins that can outperform those in today's wheat varieties.

Another WRRC team has shown that when summer temperatures reach 99° F or more (not uncommon in wheat-growing states), the genes that produce glutenin stop working. But genes that control the other major class of gluten proteins, the gliadins, stay on the job until the temperature hits 113° F. The result is that on many hot days, wheat kernels end up with a higher ratio of gliadins to glutenins. And that is the opposite of what's best for breadmaking.

To find a remedy, WRRC scientists are trying to splice the "on-off switch" in a gliadin gene to the genes in wheat that produce glutenin. If they are successful, wheat should keep on producing glutenin until the thermometer climbs to 113° F, a far rarer occurrence than a 99° F day.

In Peoria, scientists are studying the size of particles in flour after milling various types of wheat. Flour from hard red spring wheat, for example, has a different distribution of particle sizes than flour from hard red winter wheat. Researchers use air-streams of different speeds to separate the flour particles by size. Scientists say that the technique can be used to judge hardness of any wheat.

Corn

Researchers at the Northern laboratory participated with corn processors, equipment manufacturers, and experiment station scientists during the 1950's to deal with a major change in the method of corn harvesting. The change was the rapid adoption of picker-sheller equipment, which harvested only shelled corn, leaving corncobs, husks, and cornstalks in the field. For efficiency's sake, the corn had to be picked as soon as it matured, when the cornstalks were still upright and while weather permitted the use of heavy equipment in the field. Corn picked under these conditions, however, contained more than 25 percent moisture, too much to store without risking spoilage while the corn awaited its turn at the milling plant.

The answer had to be to dry corn to about 15 percent moisture soon after it was harvested with picker-shellers. Early trials showed that unless shelled corn is dried uniformly and at temperatures that are not excessively high, it will suffer damage that impairs its value as a feed and its use in both dry and wet milling.

Experiments by NRRC scientists, which accounted for about 10 percent of the total volume of U.S. research conducted on drying shelled corn, established the most suitable drying temperatures and processing conditions to prevent corn damage during drying and storage. The combined work of many engineers and crop scientists made using picker-shellers feasible, especially in large farming operations.

In the late 1950's, dry milling of corn increased in popularity. The milled products from this process were used primarily in feed, breakfast cereals, foundry binders, beverages, paper additives, and corn oil. In this area, too, NRRC scientists worked closely with industry to perfect and improve dry milling. Investigations centered on degermination processes, increased corn oil recovery, more uniformity of products, improved use of dry-milling equipment, and more efficient processing of corn handled under various conditions. The NRRC research findings were readily adopted by the dry-milling industry and have proved important in protecting increasing markets in cereal grains.

In a test kitchen at the Northern lab in Peoria, food technologist Kathleen Warner prepares breads containing 50 percent fine-ground corn flour.

Rice

Rice, a billion-dollar annual crop in the United States, is grown in only six States: Arkansas, California, Louisiana, Texas, Mississippi, and Missouri. Both the Southern and Western regional labs conduct research on rice. (See also "Fiber and Cholesterol," p.107.) Long-grain rice, an American favorite, is raised chiefly in the South; medium-grain and short-grain rice predominate in California, although substantial amounts of medium-grain rice are also raised in Louisiana and Arkansas. The United States is the world's second biggest rice exporting Nation; in first place is Thailand.

During the 1950's, SRRC scientists improved procedures for extracting rice bran oil. They also made changes in rice milling that resulted in less breakage of rice grains. A pilot plant built in New Orleans proved the value of the improvements, and they were quickly adopted by commercial mills. As the 1960's began, research on deep milling of rice produced a high-protein flour suitable for baby foods and special diets. A few years later, ways were found to recover small, thin rice kernels usually lost or broken during processing and to use them in a flour with several times the protein of regular rice.

Bread made with rice flour is readied for taste tests by WRRC food technologists Kazuko D. Nashita (left) and Laura M. Beam. Taste panels reported that the bread, which can be consumed by people allergic to wheat protein, is almost indistinguishable from products containing wheat flour.

In the 1980's, New Orleans researchers doubled the shelf life of brown rice from 6 months to at least 1 year. They also found out exactly what happens inside the rice kernel when rice becomes sticky when cooked—and how to prevent this condition. Other chemical changes, they found, have a bearing on color, hardness, and fragility of stored rice. Rice companies can use this new information to track changes in rice to determine the level of stickiness under various storage conditions. Other new SRRC data will allow processors to select specific varieties of rice for specific cooking needs.

At the Western center, scientists in the 1950's increased the capacity of heated-air rice dryers in California by 48 percent without impairing the quality of the rice. The improvements actually cut drying costs. These and other innovations saved processors millions of dollars. Since three-fourths of the rice crop was handled by cooperatives, the benefits were returned directly to growers. Researchers also developed improved ways to can cooked white rice, work that later led to a still more acceptable canned product developed by university researchers in Arkansas.

During the 1970's, Western researchers developed a way to make yeast-leavened bread from rice flour, using a gum ingredient that forms a film in the rice flour dough to make it elastic like wheat gluten. The flour was used to bake bread and other items for glucose-intolerant people. Scientists also came up with a better process for making quick-cooking rice, an innovation that had already meant a 50-percent increase in U.S. per capita rice consumption. A few years later, they developed a quick-cooking brown rice that could be prepared in one-fourth the time of raw brown rice. The processed product still retained its nutritional superiority over white rice.

Recently, a WRRC flavor chemist discovered and synthesized a chemical found in aromatic rice that imparts the fragrance of popcorn to domestic rice. Some of the world's rice crop has this natural popcorn aroma, and varieties of aromatic rice typically bring premium prices. Taste panelists judged WRRC's synthetic aroma a near match to naturally scented varieties.

Grain Sorghum

Grain sorghum, or milo, is a major crop in several States, including Kansas, Texas, Nebraska, and Missouri. As a grain and as silage, it is grown almost entirely for livestock feed.

At the Northern center during the 1940's, scientists determined the wet-milling characteristics for several varieties of grain sorghum and for both naturally dried and artificially dried grains. They also developed a method for dehulling sorghum that improved the response of the grain to wet milling and established conditions for wet-milling sorghum grits. In a few years, NRRC investigations led to development of a practical, economical method for wet-milling sorghum on a commercial plant scale.

In cooperative studies with sorghum breeders, researchers determined the content of seed-coat pigment, waxy starch, and carotenoid pigments in newly developed strains of sorghum. The NRRC findings helped industry to plan, install, and operate plants for milling grain sorghum and played an important role in making sorghum an important U.S. crop. Apart from their use in feeds, grain sorghum products have been used commercially in foods, paper, and foundry operations.

As early as the 1940's, NRRC research on wet milling and dehulling grain sorghum, shown here growing on Texas farm, helped make it an important U.S. crop.

Food for Peace

Under Title II of Public Law 480—the Food for Peace Program—the United States contributes food for hungry people in some 90 countries. When PL-480 was enacted in 1954, donations were limited to whole commodities, including wheat, feed grains, rice, wheat flour, corn meal, nonfat dry milk, and edible oil. In 1966, the law was amended to permit the enrichment and fortification of commodities to improve their nutritional quality. To develop these products, the four regional research centers, and the Northern laboratory in particular, made many important contributions. These included high-protein blends of U.S. foods for malnourished infants and children, pregnant women, and lactating mothers.

Foods donated under PL-480 today include whole commodities, processed foods, fortified processed foods, and blended food supplements. The nutritional value of several whole grains has been increased with the addition of vitamin A to help combat the blindness that has afflicted thousands of children in Bangladesh and other countries. The fortified foods routinely combine cereals and soybean meal products to increase the quality and quantity of proteins. Wheat flour, for example, is 11 percent protein; soy flour is 52 percent. In addition, the essential amino acids in cereals and soybeans complement each other; cereals are deficient in lysine, while soybeans have a high lysine content. Soybeans, on the other hand, are deficient in sulfur amino acids; cereal proteins are not. As a result, a substantial portion of U.S. donations of bulgur, sorghum grits, cornmeal, bread flour, rolled oats, and corn masa are fortified with 5 to 15 percent of soy protein.

The supplemental soy may be in the form of flakes, grits, or flour, depending on the physical characteristics of the cereal product to which it is added. In addition, all the fortified processed foods except the rolled oats are enriched with added thiamin, riboflavin, niacin, iron, calcium, and vitamin A. Much of the research on fortified foods was conducted at the NRRC,

A child in the Dominican Republic enjoys food donated by the United States under PL-480. It was prepared locally from high-protein blends developed at the Peoria laboratory.

where a process was developed and patented to convert corn and other whole grains to shelf-stable flours with improved nutritional quality.

One of the more recent fortified foods, which is popular in Mexico and Central America, is an instant corn-soya masa flour. The mixture includes a traditional masa, made by steeping corn in lime water before grinding, and 5 percent defatted soy flour. A versatile product that can be used in any recipe that calls for masa, it was field-tested for more than 1-1/2 years before being included in PL-480 programs. Peoria scientists also improved the digestibility of sorghum proteins by removing all of the grain's outer husk before boosting its protein content with 15 percent soy grits.

Blended food supplements have been used in infant and child feeding programs for more than 20 years. They were originally formulated to meet USDA nutritional guidelines by the Agricultural Research Service; they supply both calories and a substantial proportion of the protein, vitamins, and minerals that children need each day. Most widely used of the blends is CSM, standing for corn-soy-milk, that includes precooked cornmeal, defatted toasted soy flour, nonfat dry milk, soybean oil, and 10 vitamins and 6 minerals. A 3-1/2-ounce package supplies at least half the daily nutritional requirements of a preschool child. CSM can be prepared quickly with little cooking, a necessity in fuel-short countries. Peoria technologists also developed an instant CSM that can be prepared without any cooking at all. Another blend, similar to CSM, contains precooked wheat instead of corn.

Since blended food supplements for children were first exported, NRRC researchers have made several product improvements. The soybean oil content was increased from 2 to 6 percent to raise the number of calories per ounce, and various high-nutrition formulas were worked out, using different surplus grains. Storage life of the products was increased, and storage stability was predicted from time-temperature studies. Better processing was developed to destroy *Salmonella* bacteria without lowering CSM's nutritional quality, and more stable forms of vitamins A and C were found and added to the blends. Thousands of tons of blends continue to be exported each year to fight starvation and malnutrition among infants and children.

Since wheat and corn are widely grown around the world, ARS scientists hoped that Third World countries would copy the formulas for the blended foods and manufacture their own. This has occurred in several places. In one Middle East country, for instance, the government produces biscuits fortified with CSM as part of an effort to upgrade the diets of its people. In addition, a team of engineers at the Northern lab developed a five-step process that villagers in developing nations can use to make protein-rich soybean flour. Training of foreign personnel on use of the process was financed by the United Nations Children's Fund (UNICEF).

Working with a wheat food company in Seattle, WRRC scientists succeeded in developing a continuous process for making bulgur, while reducing the cost of making it by two-thirds.

In the Western laboratory, Food for Peace research focused on bulgur, a wheat product used for making pilaf, a traditional food in the Middle East. Working with a wheat food company in Seattle, WRRC scientists succeeded in developing a continuous process for making bulgur, while reducing the cost of making it by two-thirds. They also invented WURLD wheat, a chemically peeled, creamy white bulgur that looks like rice. Information developed at WRRC led to the use of bulgur in the Food for Peace program and eventually to a sevenfold increase in bulgur consumption worldwide.

Scientists at WRRC also developed Protein-Fortified Wheat Flour, Blend A, obtained by mixing 70-percent ordinary wheat flour with 30-percent wheat protein concentrate extracted from wheat milling byproducts. The result was a flour mixture with more food value, including higher lysine content, than ordinary wheat flour.

On occasion, it is the process that is exported. A new way to prepare protein concentrates from wheat and rice bran, developed at WRRC, is being used in Honduras. The concentrates, when incorporated into breads, have proved effective in combating malnutrition in children.

The Eastern lab at Wyndmoor developed another dietary supplement for children, using soy flour, soybean oil, corn syrup solids, and sweet cheese whey. The resulting whey-soy drink mix was spray-dried and fortified with vitamins and minerals before packaging for export under the Food for Peace program in the early 1970's, when nonfat dry milk was scarce and priced out of reach for Title II food donation programs. Millions of pounds of the whey-soy mix were shipped overseas at that time.

In New Orleans, the Southern lab developed a cottonseed flour with a bland flavor and a light creamy color. It was designed to be an additive to wheat flour to increase its protein content. While never used for donations in the Food for Peace program, the SRRC cottonseed flour process was introduced to the Third World through a pilot plant in India. Despite India's large production of cotton, none of the cottonseed there had previously been used for human consumption.

Fuels From Agriculture

Ethanol, or grain alcohol, burns with a pure blue flame and makes an excellent fuel for automobiles. The traditional way to make ethanol is to convert the starch from corn into fermentable sugar by cooking a corn mash and treating it with malt. The sugar is then fermented into alcohol with a yeast. The process is an old and relatively simple one, but the ethanol it produces costs more than gasoline.

The aims of NRRC research in making ethanol are to bring down its cost by using cheaper raw materials, developing processes that consume less energy, and finding more efficient yeasts for fermentation. The Northern center has made progress in all these areas. If the day arrives when ethanol is competitive in price with gasoline, U.S. dependence on foreign oil supplies will be diminished and America's trade balance will be improved. There will also be a new and profitable market for millions of tons of surplus and waste products from agriculture.

Alcohol research began at NRRC during World War II, when shortages of corn and molasses dictated finding new sources of industrial alcohol, needed to manufacture munitions and synthetic rubber. Plenty of wheat was available, but distillers had had little experience in using it to make alcohol. NRRC researchers and others soon found ways to prepare mashes from wheat instead of corn. They selected yeasts from the Peoria culture collection suitable for fermenting the mashes, and they pioneered the use of mold enzymes, called fungal amylases, to convert wheat starch into sugar for fermentation. As a result of Government-industry cooperation, some 250 million bushels of wheat were used during the war to produce critically needed ethanol.

In research immediately after the war, a survey of more than 350 fungi from the NRRC collection turned up several with promise for converting cereal starch to sugar, and the fungal amylase process for making alcohol was improved and widely adopted by grain alcohol distillers. By using fungal amylase instead of malt, they were able to reduce the cost of making ethanol by from 1 to 3 cents per gallon.

The oil embargoes of the 1970's stimulated renewed activity to find cheaper ways to make alcohol as an alternative fuel to petroleum. Microbiologists made a thorough search of the Peoria collection of fungi and bacteria to identify microbes that could do a better job of fermenting alcohol from a variety of raw materials. They knew that if gasohol were ever to become an economical fuel, they would have to find more efficient ways to convert starch to sugar and to ferment that sugar to alcohol.

The microbe screening turned up several specimens with promise. One mold, used in Indonesia to ferment a popular food product, produced glucose when grown on cracked corn. Another, a bacterium, saved energy by tolerating the heat of cooked mash better than yeast. A fungus called the oyster mushroom freed cellulose for digestion to sugar, and yet another, found in a cow pasture, performed in a similar manner, exposing more cellulose for sugar conversion. In 1982, a yeast called *Candida wickerhamii,* originally found in Italy, proved capable of making alcohol directly from cellulose, a feat that ordinary yeasts were unable to perform.

Peoria chemical engineer Patricia J. Slininger and A. A. Lagoda, engineering technician, prepare a fermentor for growing cells of Pachysolen tannophilus, *an unusual yeast that can convert biomass to alcohol.*

The most promising candidate so far for converting biomass to alcohol, however, is *Pachysolen tannophilus,* an unusual yeast from France. Through a patented NRRC process, the yeast can convert xylose, or wood sugar, directly to ethanol. That's good news, because there is no shortage of xylose on the farm; it is a major component of straw, cornstalks, hulls, corncobs, and other plant residues. A chemical engineer in Peoria is now engaged in developing a continuous process for producing ethanol with *P. tannophilus.*

Other NRRC researchers have investigated using vegetable oils—or chemicals derived from them—as diesel fuels, especially for emergency use. In short-term tests, such oils performed well in diesel engines. They did less well in longer trials, however, because of high viscosity and low volatility of soybean and other vegetable oils. Low volatility is one cause of incomplete combustion; the oil is inefficient and leaves harmful residues. Highly viscous oil clogs mechanical engine parts and causes them to wear out faster. So far, NRRC researchers have been more successful at finding ways to lower the viscosity of vegetable oils than they have at increasing their volatility.

Four possible ways to improve performance have been explored, including: (1) Chemically converting the vegetable oils with alcohols to simpler chemicals called fatty esters; (2) mixing the oils with alcohols and water to form stable blends called microemulsions; (3) dissolving vegetable oils in conventional diesel fuel, and (4) heating the vegetable oils to break them down to a variety of chemicals with lower boiling points, or higher volatility. As 1991 began, however, the problem of incomplete combustion remained unsolved. Basic research is under way at NRRC today to provide researchers with a better understanding of the chemistry of combustion. With that information, scientists believe that it may yet be possible to design technologies to improve the combustion of diesel fuels derived from vegetable oils.

Corn and Wheat Starch

Starch, the main constituent of grain flours, is the most important industrial cereal product, and the most plentiful and widely used of the starches is cornstarch. Although most of the products from corn milling go into food and feed, the industry also produces 4.5 billion pounds of starch annually, largely for nonfood purposes. Of this amount, 3.5 billion pounds are used in the paperboard, paper, and related industries, where starch serves both as an adhesive and coating.

Several hundred million additional pounds of cornstarch products are consumed each year by the textile industry, chiefly as a warp sizing to strengthen warp yarns and improve their resistance to abrasion during weaving. Cornstarch and the materials derived from it are used in countless other ways by industry, according to an NRRC starch chemist, "to thicken, stabilize, flocculate, absorb, coat, adhere to, dry, and moisten." He adds that it seems certain that if research continues at current rates, many new and expanded industrial markets for cornstarch will be found in the years just ahead.

Chemical research to find new uses for surplus corn began in 1940 with the opening of the Northern center. An early discovery involved the starch in so-called waxy corn. Most cereal grains are roughly classified as waxy and common, or nonwaxy. The terms do not imply the presence or absence of wax, but rather describe the appearance of the inside of the kernel. Peoria researchers discovered that the starch in waxy corn is composed almost entirely of a constituent called amylopectin. The amylopectin content in nonwaxy varieties is only 73 percent. Waxy cornstarch, unlike nonwaxy, is a competitor with imported tapioca in food and industrial markets, since it produces pastes with similar viscosity and clarity. Peoria researchers developed ways to process the waxy corn and found outlets for the amylopectin starch produced from it. As early as 1942, waxy corn became a profitable commercial crop, grown under contract with an assured market.

A flake of Super Slurper swells into a soft, rubbery chunk that is 99.5 percent water.

Further research disclosed that amylose, the other principal constituent of cornstarch, also has properties of value to industry. A starch composed mostly of amylose, for example, is able to form thin films. A cooperative breeding program soon led to a variety of corn with starch containing more than 70 percent amylose, compared with only 27 percent in common yellow dent corn. Buyers for high-amylose starch were found among manufacturers of glass fibers, paper, products, and specialty films. In a short time, several million pounds of the starch were being produced by the wet-milling industry, and like growers of waxy corn, farmers were producing the high-amylose corn under contract to industry and receiving premium prices.

NRRC researchers in the late 1950's discovered and developed a low-cost process for preparing a new product called dialdehyde starch from ordinary cereal starch. Enthusiasm for dialdehyde starch mounted in the early 1960's, as more and more uses for the product were found by science and industry. It imparted wet strength to paper, including facial tissues; it served as a coating adhesive for other papers; it proved an excellent tanning agent for sole leather. Called by some "a wonder product," dialdehyde starch could also harden gelatin and impart water resistance to glue for making plywood. And it was nontoxic, colorless, and odor free.

What's more, Peoria scientists improved the product in 1974, making it of even greater potential value to the paper industry. What happened? After a brief flurry of interest by U.S. industry, foreign companies began making dialdehyde starch, and today this country must import all it needs. "It was a disappointing outcome for an excellent invention," says a retired Peoria chemist.

But new uses for starch kept coming in the 1950's and 1960's. Wheat flour was chemically modified to mix readily with water to form a free-flowing paste with less tendency to thicken and gell. The improved properties made it useful as an adhesive and as a coating and sizing for paper and textiles. A versatile product with similar properties was cross-linked dicarboxyl cornstarch, which produces a variety of viscous, pastelike products that also have the desirable property of not gelling

Starch Facts

Starches, like sugars, are carbohydrates, and in many plants, starch is the form in which carbohydrates are stored. Starch is a polymer; that is, a compound in which the molecules are built up by the chemical union of hundreds or even thousands of identical molecules of a simpler substance. In the case of starch, the building block is the simplest of the sugars: d-glucose, or dextrose.

Dextrose is produced by photosynthesis in the green leaves of plants in the presence of sunlight. It combines with itself chemically through a dehydration reaction to make the long-chain starch molecule. Through a simple process called acid hydrolysis, the starch can be broken down again into molecules of dextrose. It can also be digested in the body by enzymes. (See also "Micro-organisms," p. 134.)

Starch occurs as small granules that are easily separated in pure form from the rest of the plant. It was prepared from wheat as early as 184 B.C. In 1840, Orlando Jones, an Englishman, developed wet-milling to recover starch from corn and founded a multimillion-dollar industry. By 1880, his process was used in the United States to produce 200 million pounds of cornstarch a year. Today all cereals can be wet-milled with some variation of the process.

Peoria chemist Felix Otey stretches a sheet of biodegradable plastic film, made from starch and petroleum-based polymers.

A few of the growing number of commercial products containing starch-derived Super Slurper are shown by three of the NRRC chemists who developed it: (left to right) William M. Doane, George F. Fanta, and Edward Bagley. Not pictured is team member M. Ollidene Weaver.

when cooled. And new starch-based polyesters were developed for use in making rigid urethane foams.

One of the most commercially successful cornstarch products to emerge from the Peoria laboratories was developed and improved and improved yet again. Spurred by the oil shortage in the 1970's, scientists were searching for polymers made from farm commodities to replace those derived from petroleum. In one series of experiments, they married starch to a synthetic chemical and created a product able to absorb hundreds of times its own weight in water. The chemical family name was hydrolyzed starch-polyacrylonitrile graft copolymers, but somebody dubbed the absorbent Super Slurper, and the name stuck. After USDA patents were secured in 1976, Super Slurper began to be employed for a variety of practical uses, and the starch-based industry grew rapidly.

One company, which was licensed to use the USDA patents, now markets a product for agricultural uses under the trade name STA-WET. It is used to jacket seeds to accelerate germination and increase yields and to coat the roots of trees before transplanting them. Both techniques hold water where it is needed. Another firm, marketing Super Slurper under the name STA-DRI, uses it to remove water from fuels; still another manufacturer incorporates the product in fuel and oil filters. One company markets baby powders and wound dressings containing the absorbent, and compounds very much like it are being used in disposable diapers and sanitary napkins.

New and original uses are still being found for Super Slurper. An ARS entomologist in Florida recently discovered that the water-hungry product, when added to the soil in citrus groves, keeps dry soil moist so that tiny nematodes can survive during dry spells to kill weevils that chew up citrus tree roots. (The nematodes invade a weevil's gut and release lethal bacteria.) The scientist suggests that commercial companies rear the helpful nematodes and package billions of them alive. Growers could mix them with Super Slurper and apply them to citrus tree roots before planting, he says, providing a grove of trees with built-in weevil control around the roots.

In still other applications, the absorbent compound, which has been improved until it slurps up 2,000 times its weight in water, is being used as an electrical conductor in batteries and in medical and recreational cold packs. The NRRC invention has already led to creation of a $1-billion-a-year industry, and sales could top $3 billion a year before the year 2000.

Another major discovery at the Peoria lab in the 1970's was insoluble starch xanthate (ISX), a starch-sulfur compound used to remove heavy metals from wastewater. Discussed in more detail in the chapter on "Waste Management," p. 28, ISX is now being used to treat processing wastes of the electroplating and circuit printing industries. The compound lowers the heavy metal content of discharge water to allowable levels.

Another NRRC inventor patented several processes in the 1980's for encasing sticky particles of latex in a thin film of starch-based compounds. The result is a lightly powdered latex that is nontacky and free-flowing—both useful qualities in making tires and other molded rubber products. The starch in this application is used in amounts too small to make it a filler, and it has little or no effect on rubber quality. Other NRRC research, however, showed that starch could replace carbon black as a filler in tires and could be used to make rubber in various colors.

The Science of Rheology

Factories that saw boards or punch out sheet metal parts or assemble bicycles all have something in common. The materials they work with don't keep changing their form and density during manufacture. But that isn't true of many other materials, like plastics and bread dough and cheese and confections. During processing, such materials may swell or stiffen or flow or ooze or creep or soften or droop. They present so many special industrial problems that a whole science has developed to study them—a branch of physics called rheology.

The word was coined by a chemist in 1928, and a year later The Society of Rheology held its first meeting. Rheology is defined as "the study of the change in form and the flow of matter, embracing elasticity, viscosity, and plasticity." Rheologists, like scientists in other disciplines, have evolved a vocabulary of their own, including terms like "relaxation rate" and "dilatant," which means expanding in bulk when the shape changes. They often work with viscous materials that are somewhere between the solid and liquid state. In Peoria, rheologists have applied their special expertise to help commercial bakeries bake bread from different wheats; to characterize the properties of starch gels, to manufacture xanthan gum, and to meet similar challenges that involve materials, like rising bread, that change form and shape during processing.

Encapsulating various products in granules of starch is another NRRC-developed process that appears to have an exciting commercial future. The idea was originally developed to allow the slow release of herbicides and other chemical pesticides. There are many benefits to farmers in using such products. Smaller amounts of chemicals are needed to kill weeds and

Twin-Screw Extruders

A tool that has captivated several Peoria researchers during the last 2 years is the twin-screw extruder. Used today in several industries, it consists of two big horizontal screws, which may intermesh or not, rotating in either the same or opposite directions. As the screws rotate, they can mix various high-solids materials and move them along through chemical reactions, eventually extruding them. In the food, feed, plastics, and rubber industries, the extruders have often replaced mixing materials in batches, a step that breaks the continuity of processing. "A twin-screw extruder," explains an NRRC chemist, "represents a low-energy way to process very viscous and hard-to-mix materials in continuous in-line reactions. You can put a complex series of reactions into a closed system."

In the laboratory in Peoria, twin-screw extruders have been used successfully to convert starch to much smaller molecules that act as chemical precursors in making a variety of products, including polyurethane foams. The reverse is also true: extruders have been used to build onto starch molecules, to increase their molecular weight.

Twin-screw extruders can also be used on an industrial level to make starch graft polymers, including Super Slurper. "It used to take an hour or more to make a batch of the product," says the chemist. "With a twin-screw extruder, it can be made in a continuous process in a matter of minutes. In terms of capital cost per pound, it is far cheaper to make Super Slurper with a twin-screw extruder than in batches." Another successful NRRC application is in encapsulating various chemicals, including pesticides, in a starch for slow release. The whole process can be carried out in a single operation with extruders.

"Extruders are wonderful, flexible processing tools," concludes the scientist. "You can change their pitch, alter their speed, run them forwards or backwards, drop in chemicals to react at any point in the process, and add sections to knead the materials." In current NRRC research, they are being used to produce starch-plastic premixes for blown films.

insects, pesticides stay active longer, and they cause less pollution because they are not washed away or leached into the ground as easily as unencapsulated chemicals. The starch jackets also protect the pesticides from decomposition from sunlight and rain.

To encapsulate a herbicide, cornstarch is cooked in a jet of steam to gelatinize the starch; then the chemical is mixed in. After drying, the mixture can be crumbled into free-flowing granules or ground to any size of particle.

Since its initial development, NRRC researchers have come up with many more uses for starch-encapsulation of liquids and solids. Their patented invention employs a low-amylose matrix that, like other cornstarch products, can be used in foods. As a result, says a Peoria chemist, "the number of products that could be profitably encapsulated is limited only by the imagination. You could use slow-release capsules for insect lures, plant growth regulators, fertilizers, medicines, vitamins, and food flavorings and colorings. And all of them using a product made from surplus corn!"

In 1990, two NRRC researchers reported that adding starch and sugar to a spray of *Bacillus thuringiensis* (Bt) helped prevent the bacterium from being washed off plant leaves by rain. Bt is a biocontrol that is effective against several insect pests of crops. Without the sugar-starch mixture, Bt remained on corn leaves for only 4 days before becoming ineffective. With the mixture, it stayed put and kept killing European corn borers for up to 19 days, rain or shine.

Much of the most sophisticated chemical research conducted at the Northern laboratory in the last few years has been directed toward incorporating starch into plastic films derived from petroleum. Many farmers and gardeners today blanket the soil between crop rows with black plastic mulch to warm the soil and retain moisture. Millions of pounds of plastic films are sold each year for this purpose. The trouble is that the plastic doesn't biodegrade in the soil. It has to be removed when no longer needed and burned or buried. A similar problem exists with plastic trash bags buried in landfills. They remain there indefinitely. The inclusion of enough starch in the plastic films, reasoned Peoria chemists, might well make the mulch and trash bags biodegradable.

Research along these lines has so far led to one invention that is clearly a success. Technology developed by NRRC scientists is being used by a company in Indiana to produce starch-based laundry bags that will dissolve in hot water. The products are finding a ready market in hospitals, where the water-soluble bags protect patients and hospital workers from the danger of cross-contamination from soiled linens. Laundry can be placed directly into washing machines in sealed bags, which soon disappear.

A more difficult research task is the development of trash bags that will break down in the soil. Two major chemical approaches have been used to include starch in the formulas, and both produce plastics with satisfactory strength. As early as 1985, studies showed that it is possible to devise starch-plastic formulations that can withstand the strain of extrusion-blowing into plastic film. The films, however, are only partially biodegradable. The higher the proportion of starch in the plastic, the more it will either disintegrate or break down into simpler compounds. That part of the formulation derived from petroleum, however, biodegrades much more slowly. Researchers still hope to crack the puzzle. Or it may be that someday, labeling for plastic bags will disclose the percentage of the product that will biodegrade.

Recent experiments have used wheat starch instead of cornstarch in trials with biodegradable plastic films. One type of wheat starch granule is less than half the size of a granule of cornstarch and, theoretically at least, could be used to make thinner plastic films. "The first need," explains a Peoria chemist, "is a practical way to sort out the really small granules that would go into such plastics." Researchers at the Southern center in New Orleans think they may be able to handle the sorting for Peoria with their liquid cyclone, originally used to remove gossypol glands from cottonseed meal.

Proteins in Milk, Grains, and Oilseeds

Compared with scientific understanding of carbohydrates and fats, relatively little was known 50 years ago about the chemistry of proteins. "Of all natural products," wrote a chemist in Peoria during the early years, "the proteins present the most complicated puzzle with which science has to deal." Since then, of course, the body of knowledge about protein chemistry has been expanded enormously. A significant part of this increased understanding has been acquired through research at the four ARS regional laboratories. Following is a sampling of some of the more important discoveries that have taken place during the last half century in Peoria, Albany, Wyndmoor, and New Orleans.

Milk. In cow's milk, casein is by far the most abundant protein, and it was one of the first studied in depth at the Eastern laboratory. For a long time, casein was thought to be a simple substance, but ERRC scientists soon learned that this was a misconception. Early analytical tools were just too crude to reveal its complexity. For example, "simple" casein was eventually found to contain four component proteins: alpha-, beta-, kappa-, and gamma-casein. Further investigation revealed still greater complexity in alpha-casein, which contains both calcium-sensitive and calcium-insensitive fractions. It is the interaction of these four proteins that creates the colloidal complex that transports calcium, an essential mineral in our diets.

Examination of milk from individual pedigreed cows revealed still more casein types—mutant forms known as genetic variants. ERRC researchers tracked the presence of these variants in different breeds and blood lines, observing their relative abundance, the chemical differences in their molecules, and their relationship to the quality of milk and milk products. This research provided important information in the genetic study of dairy cows and led to practical improvements in milk processing.

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Alphabet of Life

Amino acids are sometimes called the alphabet of proteins, sometimes the building blocks. Despite the enormous diversity of protein molecules in living things and their great size (hemoglobin in human blood has a molecular weight of 63,000), all are made up of combinations of 20 standard amino acids. The human body can manufacture 12 of these acids from the raw materials supplied by our diet. The remaining 8, however, must be acquired readymade from the food we eat.

These 8 essential amino acids are valine, lysine, threonine, leucine, isoleucine, tryptophan, phenylalanine, and methionine. The proteins of certain foods, like meat, fish, poultry, eggs, milk, cheese, and a few legumes, contain adequate amounts of all of them and are known as complete proteins. The proteins in other foods—grains, nuts, vegetables, and fruits—are deficient in one or more of the essential acids or contain too little protein overall to meet the body's needs.

Other milk research revealed not one but three types of beta-lactoglobulin, the chief protein in whey after casein has been removed to make cheese. The types are genetically variable. ERRC scientists also developed a practical method for probing the complex molecular structure of proteins, and biochemical research revealed for the first time how casein is modified (phosphorylated) to carry calcium. This was responsible for much of what scientists eventually learned about casein and beta-lactoglobulin. The findings have led to new insights into the use of milk proteins as food ingredients with high nutritional benefits.

Wheat. Like other grains, wheat is a nutritionally incomplete protein, deficient in lysine and threonine, two essential amino acids. Nevertheless, it provides 15 percent of the protein in the U.S. diet. One reason for wheat's popularity is that, thanks to the elasticity of its gluten, it is the only grain besides barley (which doesn't do it nearly as well) and triticale (a cross of wheat and barley) that can be made into a bread dough that rises. Gluten is composed mostly of protein.

Scientists at Peoria began fundamental research on wheat gluten in 1955, seeking to establish a basis for determining wheat quality. Their work resulted in a long list of firsts. They were the first to isolate and characterize wheat gliadins, one of the two protein fractions that make up gluten. They were also the first to isolate subunits of wheat glutenin, the other fraction in gluten. It is the glutenins that contribute most of the strength and viscosity to flour doughs and make wheat flour so useful for bread and other bakery items. This basic information has helped industry to use and control the properties of gluten proteins and of the wheat products that contain these proteins (see "Wheat, Flour, and Bread," p. 109).

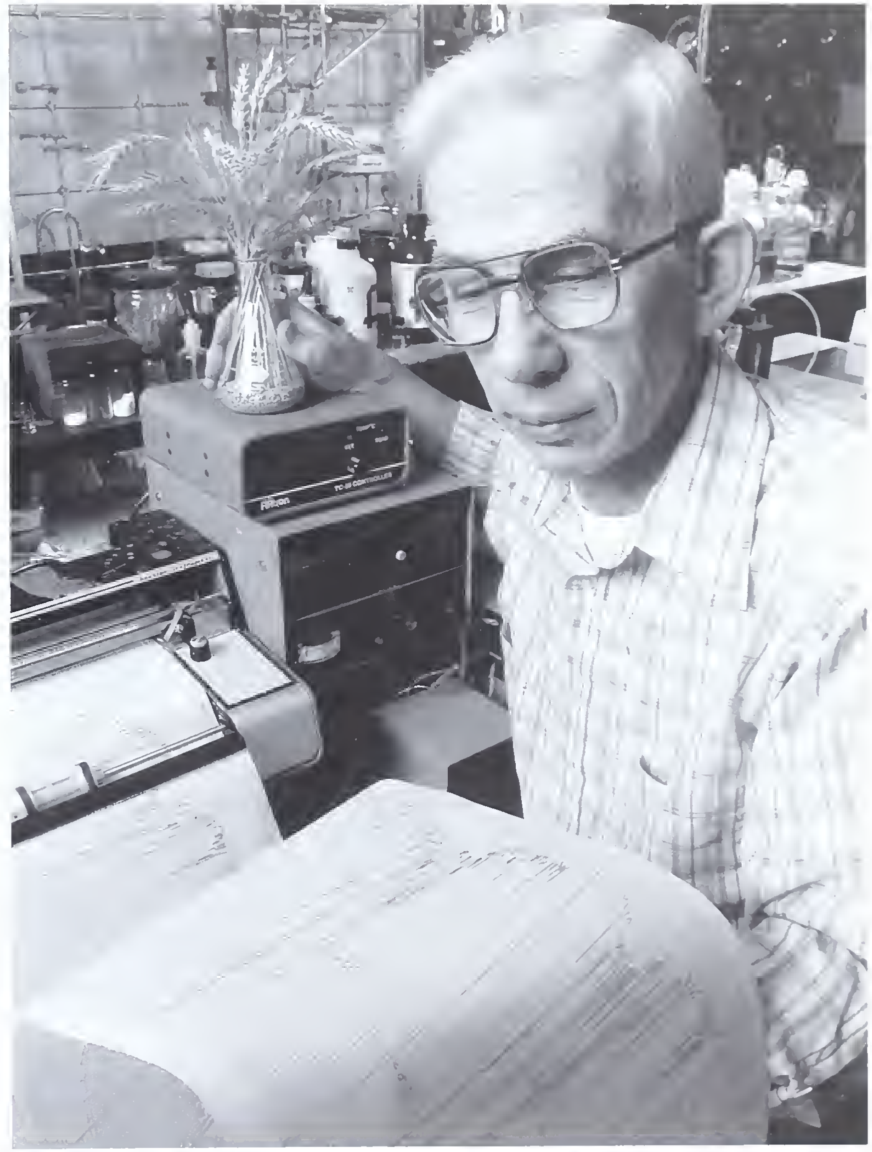
NRRC researchers were also the first to use high-performance liquid chromatography to analyze wheat proteins. A procedure using the same instrumentation was later developed to identify different wheat varieties by analyzing the levels of individual proteins in a single kernel of wheat. The method, which is fast and reproducible, is comparable to fingerprinting and aids the wheat breeder by identifying desirable genetic characteristics. It continues to provide important information for wheat researchers.

But much more remains to be learned about wheat proteins. Learning how gluten fits together and interacts with other food components in bread is one of the greatest challenges confronting protein chemists. One researcher explains that gluten has some 100 to 200 different subunits joined in an "incredible number of combinations" that affect the nutritional and physical qualities of the proteins.

The Western laboratory has also conducted research on wheat proteins, focusing most recently on opening the way to making genetic improvements in the grain. Through gene sequencing and direct protein sequencing, WRRC researchers have learned how gluten proteins determine the unusual elastic properties of doughs—and why there are important differences in these properties among various wheat varieties. In the laboratory at

It is the glutenins that contribute most of the strength and viscosity to flour doughs and make wheat flour so useful for bread and other bakery items.

Oat protein, isolated and concentrated by chemists Y. Victor Wu (left) and James E. Cluskey and their associates, has the best amino acid balance of the cereal proteins.



In Peoria, chemist Floyd Huebner separates proteins of hard red wheat using a high-performance liquid chromatograph.

least, scientists have modified the amino acid content of major proteins in the wheat kernel through gene manipulation. Objectives are to enlarge the natural germplasm base of wheat and to make improvements in the grain that would be practically impossible with traditional breeding methods. Future improvements, of course, will ultimately require the help of plant breeders.

In other WRRC research, a new biotechnology probe comprises antibodies that seek out and bind to wheat glutenins. It may prove a faster, easier way to track and measure these protein fractions.

Corn. While the bulk of each year's corn crop is used directly as feed for farm animals, some 1.2 billion bushels, or about one-sixth of the harvest in a typical crop year, is used for human food here and abroad, to make alcohol, corn sweeteners, and industrial products, and for seed. Corn gluten, a byproduct of cornstarch refineries, contains about 50 percent protein, and much of this product is also used in feed concentrates for animals. NRRC scientists, however, have worked long and hard to develop industrial uses for corn proteins, with varying degrees of success.

Of particular interest to NRRC scientists in the 1940's and 1950's was zein, an alcohol-soluble corn protein first produced commercially in 1938. In 1945, Northern lab researchers developed a complicated method for extracting zein from corn gluten meal. By 1948, industry was using the process to produce zein for many industrial purposes.

For a time, when the corn protein was competitive in price with other protein sources, zein was used with resin and alcohol to make varnish. It was also used as a substitute for shellac in phonograph records, as a binder in composition cork, and for dozens of other uses in making paper and paperboard, gaskets, coatings, and adhesives. In 1948, it was even made into a warm, durable textile fiber—Vicara—which was used in fabrics alone or in blends with rayon, nylon, and wool. After years, however, the zein in many industrial products was replaced by lower priced compounds, including petrochemicals.

WRRC food chemist Linn P. Hansen compares standard-process rice flour, in container on left, with enzyme-treated CHP rice flour that has three times more protein.

Much of the concern of agricultural scientists over corn protein has centered on keeping its content high in feeds and food. In the mid-1950's, an NRRC chemist observed that the protein content of the U.S. corn crop since the mid-1930's had fallen from about 11 percent to an average of less than 10 percent. Further study convinced him that the amount of protein in corn was strongly influenced by climate, and in particular by lower average temperature. His findings led to more intensive study of the impact of weather and hybridization on corn nutrients and were of great value to breeders.

Within several years, breeders had developed new varieties of corn with higher protein content, but the new lines were often too soft for efficient milling. Analytical data from NRRC researchers, much of it obtained through the use of sophisticated techniques and instruments, led to the development of new lines with good nutritional properties and harder kernels. These higher protein corns have proved valuable for many uses, including inclusion in CSM, a corn-soy-milk blend exported for the Food for Peace Program (see "Food for Peace," p. 116).

In 1973, NRRC cereal chemists developed dry-milled corn germ flour, a new product. It was a significant new source of iron and other minerals and of protein, including the amino acids lysine and tryptophan. Taste panels agreed that in cookies and similar baked goods, corn germ flour could replace 25 percent of less nutritious wheat flour with no discernible change in taste or texture of the products. In 1976, one company began making and marketing the flour, but after the death of the firm's owner, it was no longer produced in this country. Currently, there is interest in food products containing protein recovered from corn stillage after starch is converted to alcohol.

Soybeans. As early as the 1940's, it was evident that oil-free meal from dehulled soybeans, a produce with about 50 percent protein, is a raw material with several important industrial applications. By 1950, it was used to make as much as 45 million pounds of waterproof soybean meal glue for fabricating plywood. It also found a market in coating wallpapers, and later found use as a glossy coating for top-quality printing papers.

The first important use of soybean protein in human foods came in 1950 with the invention at the Northern lab of an edible high-protein product, the result of extracting oil from soybeans with ethanol, or ethyl alcohol. The alcohol extraction method improved the color and taste of the meal and of the protein isolated from it. The new NRRC product, which was made from alcohol-washed defatted soybean flakes, was named Gelsoy; it was 55 percent protein and 45 percent soluble carbohydrate. In solution with water, it could be whipped into a meringue like egg white or used in ice cream as a vegetable gel. Within a few years, it was discovered that Gelsoy could be used to impart more softness to bread, a quality prized by many consumers. The product was soon being produced by a Peoria miller.

A short time later, the hexane-and-alcohol method for extracting soybean oil led to development of several products produced commercially: a soy flour, a protein concentrate, and a textured protein concentrate. The flavor of these products was so improved over early examples of soy flours and extenders that by 1979, all ground beef purchased by the U.S. military was extended 20 percent with textured soy protein. The products were used in schools, nursing homes, and institutions, and proved popular as a source of protein for vegetarians.

A new type of soy concentrate was isolated from full-fat soy flour in the mid-1970's by a chemical engineer in Peoria. The concentrate could be reconstituted easily with water to make a bland, smooth soy "milk" for feeding babies allergic to cow's milk. It could also be used in other beverages, including thick milkshakes. The concentrate retained 94 percent of the protein and 85 percent of the oil in soybeans, and cooking the soy inactivated enzymes that would limit shelf life.

At the Southern center, researchers have modified soy proteins with enzymes to improve the solubility of soy flour and its ability to form emulsions. The enzyme treatment, which is now being evaluated by industry, may extend the use of soy flour in coffee whitener, salad dressings, and protein-fortified beverages.

Meanwhile, soybean researchers at several labs, including the NRRC, have been zeroing in on the plant's production of oil and protein. By 1991, three soybean genes had been cloned that are

Proteins

Protein is an essential constituent of all living cells, plant and animal. The human body is about 18 percent protein. It is needed to build body tissues and to construct hormones, enzymes, and genetic materials. Protein is one of the most complex of all organic substances.

Proteins are composed almost entirely of the elements carbon, hydrogen, oxygen, and sulfur. Some contain small amounts of phosphorus and other elements. Most plants make their own protein from photosynthetic products and inorganic nitrogen from the soil. Animals, including people, have to get their raw materials for building proteins—the amino acids—either by eating plants or other animals.

The number of different proteins in plants and animals is astronomical. There are 3,000 in a common bacterium, *E. coli*; there may be 100,000 in a human being. But the proteins in each kind of living thing—a house fly, a dandelion, a goat—are unique to that species, although there are amazing similarities in closely related species.

Proteins in agricultural products include albumin in eggs, gluten in cereals, casein in milk, keratin in feathers, collagen in hides, and other proteins in the various oilseeds. Essential to our diet, proteins are also used for a variety of industrial purposes.

important to the production of hitherto scarce amino acids essential to human nutrition. Today, soy protein products, including infant formulas, make a moderate-sized industry.

Cottonseed. Researchers at the Southern center in the 1980's developed a simple, air-separation process for making an edible, 65-percent-protein flour from cottonseed. It reportedly has chemical and physical properties that make it attractive for use in food products. It also meets standards for free-gossypol content of the Food and Drug Administration and the UN's Protein Advisory Group. SRRC engineers say that the flour's price in most years would be competitive with the price of soybean protein concentrate.

Rice. Scientists at both the Southern and Western labs have developed high-protein rice flours. The SRRC uses an overmilling procedure to remove the protein-rich outer surface of the rice kernel for use in its product. The WRRC uses an enzyme obtained from a mold, *Aspergillus oryzae,* to produce CHP (chemically high protein) rice flour from standard rice flour.

Oats. Chemists at the Northern lab isolated and concentrated oat protein in the mid-1970's. The product has a bland taste, good nutritional value, and can be produced in commercial quantities. Researchers foresee using oat protein in meat products and in baked goods, where it can hold moisture to help maintain freshness.

Safflower. At the Western lab, scientists invented a new process for extracting protein from safflower, an oilseed plant that is tolerant of drought. In many applications, the protein is said to exceed the standards set by users of soy-based protein. The safflower protein isolates are suitable for enriching pastas and carbonated beverages. Spin-off research was under way in 1991 to make use of the protein to fortify tortillas made from corn or wheat flour.

Peanuts

U.S. farmers produce from 3 to 4 billion pounds of peanuts annually. About 40 percent go into processed foods, including salted peanuts, candy, snack crackers and cookies, and, of course, peanut butter. America's love affair with peanut butter has lasted for many years and shows no signs of cooling off. Its smooth and crunchy varieties chew up about 700 million pounds of peanuts a year. Peanut butter is a mainstay of the School Lunch Program and is popular with both children and nutritionists. The latter point out that a pound of peanuts contains more protein, minerals, vitamins, and calories than a pound of beefsteak. The U.S. peanut industry also crushes about 400 million pounds a year for oil. The residue, peanut meal or cake, goes mostly for animal feed.

Peanuts have been the object of scientific study at the New Orleans regional laboratory since the early 1940's. The primary goal, then as now, was to improve peanut flavor and quality and to help increase peanut consumption. Another aim in the early days was to diminish the surplus of peanuts by developing new industrial uses for peanut meal and protein. And the South's research chemists did just that. Among the peanut protein products that came from the SRRC were glues, coatings for paper, a fire-extinguishing liquid, and sizings for paper and textiles. Chemists even made a textile fiber from peanut protein. Called Sarelon, it was soft and blended well with rayon or wool. It enjoyed a brief commercial existence before being supplanted by synthetics derived from less expensive materials.

More lasting success came with the discovery of ways to extend the shelf life of peanut products, since the high ratio of unstable fatty acids in peanuts once caused unpleasant flavor changes. The quality of peanut flavor is best preserved, researchers found, when kernels are properly dried immediately after harvest. They demonstrated that an optimum drying temperature minimizes development of off-flavors.

Partially defatted peanuts, the result of SRRC research, contain only half the calories of ordinary roasted peanuts but retain the high protein content and irresistible flavor.

Somewhat later, peanuts grown on four different continents were collected and analyzed, using instruments to detect substances that contribute to flavors. Experienced sensory panels evaluated flavor quality. The study showed clearly that U.S.-grown peanuts have the fewest off-flavors and the most peanut flavors rated as desirable. This information is used to market U.S. peanuts abroad.

Another problem solved was the loss of part of the peanutty flavor in partially defatted peanuts and in salted peanuts after roasting. To restore flavor, researchers first had to determine exactly what constituted peanut flavor and how much of each constituent was present in a full-flavored peanut. More than 200 different compounds were eventually identified in peanut flavor concentrates.

SRRC investigators in time perfected a process for removing part of the oil from the peanut without serious loss of flavor. They also succeeded in returning the lower calorie peanut to its original shape by expanding it in steam before roasting. Partially defatted peanuts are now sold by several companies, and the market is growing.

In marketing peanuts, the amount of moisture in the kernels is extremely important in determining the price. An SRRC-developed process for determining moisture content was adopted by the American Oil Chemists' Society and by peanut traders as their approved method. The Southern lab's expertise in testing was also put to work during the 1970's to analyze the composition of 20 different peanut protein products developed by various State and industrial laboratories. The products included flakes, flours, concentrates, and isolates.

Most consumers who have nibbled on the familiar red-skinned peanut are unaware of the existence of a white-skinned variety. They are rarely grown commercially because they are relatively flavorless. It was this very lack of flavor, however, that led two ARS chemists at the Southern lab to make them into peanut flour. The result was a white, tasteless flour containing five times as much protein as wheat flour.

U.S. Crops in Asian Foods

Japan for many years has been America's number one customer for soybean exports. During the 1950's, however, that lucrative market was threatened. The Japanese use the whole bean in preparing foods like tofu and miso, a paste that is usually added to soup and generally eaten twice a day for protein and flavor. Complaints came from importers about certain characteristics of U.S. soybeans, such as broken beans, uneven cooking, dark-colored products, and undesirable beany flavors. Other Asian nations also reported difficulties in preparing traditional foods with American soybeans. Researchers at the Peoria laboratory were asked to evaluate typical U.S. soybeans in Asian foods.

The research, part of a market development program of USDA's Foreign Agricultural Service and American Soybean Association, was carried out with the help of Japanese food technologists. The NRRC team first cracked soybeans into grits and removed the seedcoats, cutting the fermentation time in half. Seedcoat removal, it turned out, eliminated the greatest single cause of the unsuitability of some American soybean varieties. It removed any black hila, or eyes, which caused objectionable dark spots in the miso, and it increased both protein content and uniformity. In time, miso made in the Peoria laboratory was judged equal in quality to the Japanese product.

Tofu, a soybean curd now familiar to American consumers, is make by soaking, wet grinding, cooking, and filtering soybeans to produce an emulsion. A chemical is added to coagulate the protein and the oil. The tofu is molded into a soft, white cake used in soup or fried in deep fat. The Japanese Ministry of Agriculture evaluated American soybean varieties and judged several equal to Japan's for tofu production. Japanese imports of U.S. soybeans began to climb, until today Japan buys about 4 million metric tons a year. And tofu, frozen and otherwise, caught on in the American market. NRRC has been the major source of technical information for this expanding new American business.

Researchers in Peoria helped expand the Japanese market for U.S. soybeans by finding ways to make acceptable versions of popular Asian foods like tofu, a soybean curd.

NRRC research continued on fermented foods popular in Asia. Scientists learned to make tempeh, a traditional Indonesian food made in that country by fermenting soybeans wrapped in banana leaves. A mold, *Rhizopus oligosporus,* transforms a practically inedible cake of beans into a flavorful, easily digestible food. Tempeh, which is always heated before eating, can be sliced and fried or cut up and added to soups and stews. The NRRC team experimented with it and came up with a flavorful tempeh made from wheat and soybeans. The protein content of the improved tempeh was more balanced than that of tempeh made with wheat or soybeans alone. Tempeh can also be made from oats, barley, rice, and rye.

Further NRRC soybean studies produced American versions of many more oriental foods, including sufu, a Chinese soybean cheese, and kori-tofu, a dried soybean curd popular in Japan. Experimenters even developed a couple of new fermented soybean items—hakko tofu, a high-protein food with smooth texture and relatively bland flavor, and soy yogurt, made from an improved soy milk. These products may yet appear in American supermarkets.

Meanwhile, at the Western lab, food researchers were turning out moist, Chinese-style steam bread and noodles to find out how flour from California wheats measured up. Chinese bakers had complained that flour made from some California hard red wheats made the dough too sticky. A food technologist blended a hard white variety of wheat with the red. The resulting flour gave steam breads the smooth, glossy-white finish prized by bakers in China, and it proved just as acceptable for noodles. The wheats are now exported to China under the name California Blend.

Another WRRC scientist has developed a process to reduce the salt in soy sauce by 50 percent. He also increased the potassium content five times without sacrificing the sauce's rich flavor or causing bitterness. High salt intake has been linked by medical researchers to hypertension. The new WRRC technique works not only for soy sauce but for other high-sodium, fermented liquids as well, including oriental fish sauce and tamari sauce.

The Extraordinary Enzymes

Enzymes are very large protein molecules that make possible the many complex biochemical processes necessary to maintain life. All enzymes are catalysts. They speed up and direct the thousands of chemical reactions that take place in all living things without being consumed themselves.

In human bodies, enzymes aid digestion by helping break down large molecules in the food we eat into smaller molecules. Other enzymes guide these small molecules through the intestinal wall into the bloodstream. Still others promote the creation of complex molecules to produce the constituents of our cells. Enzymes are also responsible for respiration, the storage and release of energy, vision, reproductive processes, and every other aspect of metabolism. Enzymes are indispensable to life.

Enzymes are specific; each one is able to promote only one type of reaction. Further, there is only one area or region of an enzyme that can bind its substrate. That area is known as "the active site," and the mechanisms by which substrates bind to enzymes are known in only a relatively few cases. Most extraordinary of all is the speed and efficiency of reactions catalyzed by enzymes. In a living plant or animal, an enzymatic process is typically lightning-fast. When scientists try to duplicate the same process in the laboratory, it proceeds much more slowly and is often incomplete.

Much remains to be learned about the science of enzymology. It has been only 65 years since the first enzyme was isolated, and researchers today know that each living cell contains up to 50,000 separate enzymes. Many scientists believe that enzyme research will continue to prove one of the most productive areas of biochemistry and will lead to the creation of many exciting new products and processes.

Microorganisms

Microorganisms can be identified today using DNA analysis.

One of the world's most useful collections of microorganisms is classified, stored, and maintained at the Northern Regional Research Center in Peoria. It contains more than 80,000 strains of microbes, including some 10,000 bacteria, the simplest one-celled forms of life. About 60,000 additional strains make up the fungi collection, comprising the molds and yeasts. These are nature's wrecking crews; they decompose practically everything in the organic world, permitting the elemental constituents to be used again. Housed in an ordinary refrigerator, there is also a collection of 10,000 actinomycetes, filament-like organisms that are intermediate between bacteria and the more complex fungi. These are the source of such important antibiotics as streptomycin and aureomycin. All the Peoria collections, which keep growing year after year, contain microorganisms of use or potential use to industry and agriculture.

There is much more to collecting microbes than labeling them and keeping them alive. Each has to be correctly identified to guarantee the purity of many foods and beverages that use microorganisms in their manufacture. Identification is also necessary to ensure quality control in making food supplements, vitamins, antibiotics, and other products, and to prevent contamination. Another area in which differentiating among strains of a particular microorganism is vital is in settlement of patent disputes. The ARS Culture Collection in Peoria is one of only two in the United States officially recognized by the U.S. Patent Office as a depository for cultures used in patents.

Identification of microorganisms is more accurate today than ever before because it is based on analysis of the DNA, or genetic material, peculiar to each species. Variants in genes, found in all microorganisms, are also observed and classified. This research provides the groundwork for developing molecular probes. A probe provides a researcher with a fast, simple way to recognize specific microbes and to control their presence—whether welcome or unwelcome—in agricultural products and manufacturing processes.

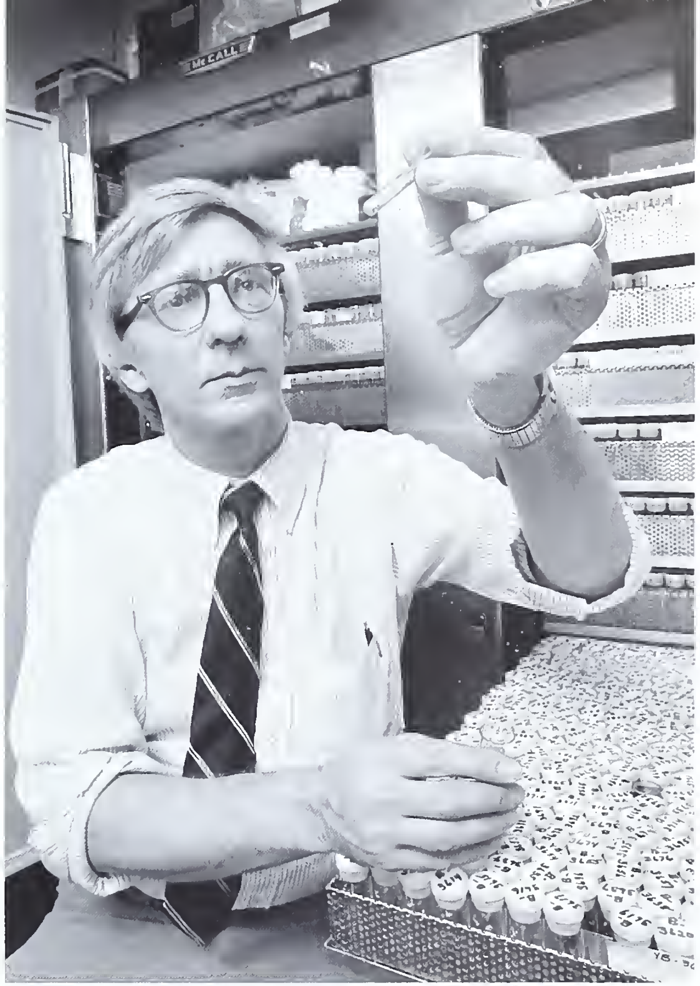
The use of species and strains from the NRRC collection has resulted over the years in accomplishments so important as to defy economic evaluation. A strain of the mold *Penicillium chrysogenum*, originally found on a Peoria cantaloupe, came from the collection and made large-scale wartime production of penicillin possible. In 1943, a variant observed by an NRRC scientist in a culture of the mold *Ashbya gossypii* was found to produce riboflavin, or vitamin B2. A bacterium, *Streptomyces olivaceus*, proved capable of producing vitamin B12 in a fermentation process, as did several other *Streptomyces* species. The fermentation process made possible production of the vitamin as a feed supplement for poultry and swine.

The collection of molds in Peoria is probably the largest in the world and unquestionably the largest that is accessible to the public. It was the source of improved strains of *Aspergillus awamori* that produced fungal amylase, used in the fermentation of starch. The process, now used worldwide, replaced the less efficient and more expensive production of amylase from barley malt. Today the ARS collection is the world reference collection for *Aspergillus*, *Fusarium*, and other important molds.

As described in an earlier chapter, Dextran, a blood extender, and xanthan gum, a valuable industrial product, were both developed from bacteria found in the Peoria collection. And *Blakeslea trispora*, a fungus first found on pumpkin, squash, and cucumber blossoms, produces beta-carotene, a precursor of vitamin A, in a fermentation process.

One of the Northern lab's earliest discoveries was a way to ferment carbohydrates with different strains of the mold *Aspergillus terreus* to produce itaconic acid. The NRRC method is still used today to produce the acid for use in manufacturing plastics, lubricants, and other chemicals. In 1950, NRRC researchers developed a fermentation process in which the mold *Aspergillus niger* is used for the direct production of sodium gluconate from corn sugar. The method not only uses surplus corn, but it brought down the price of sodium gluconate by more than 50 percent when it was commercialized in 1951. The chemical is used as a sequestering agent in glass-washing and aluminum-etching compounds. The value of this discovery, which cost relatively little in research funds, is estimated in the

At the Peoria center, microbiologist Cletus Kurtzman, curator of an ARS Culture Collection containing more than 80,000 strains of microbes, selects yeasts that can grow on sugars and other organic compounds.



millions of dollars. Another use for microorganisms is to produce plant growth hormones. One of them, gibberellic acid, speeds up plant development, including the formation of blossoms and seeds.

The curator of the ARS Culture Collection is responsible, among other things, for learning all he can about a yeast collection of 600 species and more than 14,000 different strains. "We're not just looking at them under a microscope," he explains. "We are isolating and mapping their molecular genetic materials, like DNA. The most spectacular uses of yeast in the future will be for genetic engineering, using recombinant DNA technology."

Genetic transfer is already possible using yeast as a vehicle, but better methods are needed for transferring genes from one yeast cell to another. Among other things, Peoria scientists envision using yeasts to produce citric acid more cheaply. Citric acid is an ingredient of carbonated beverages, syrup, food, and pharmaceuticals. Scientists also speculate that yeast-manufactured hormones might be developed to regulate human metabolism for weight control and that yeasts could be engineered to impart specific flavors to food, such as making a potato taste like Cheddar cheese.

But such uses as these for yeast lie in the future. Many new uses have already been discovered at NRRC. As early as the 1950's, basic research on yeasts led to a better understanding of the mechanism of yeast reproduction. These discoveries, in turn, made it possible to create improved yeasts for industry. A team of Japanese scientists then used the knowledge obtained in Peoria to breed hybrids of a yeast used in fermenting shoyu, a soy sauce made from soybeans and wheat. The hybrids not only increased the rate of shoyu production but also improved its flavor.

Brightly colored strains of a yeast called *Aureobasidium pullulans* were found to excel at releasing xylose, a sugar in plants, from xylan, a hitherto resistant component of plant fiber. Xylose, a 5-carbon sugar, is prevalent in brans milled from grains and in food processing wastes. It makes up 25 percent of the 500 million tons of crop residues produced each year in the United States. It is also found in paper-milling wastes. (See also "Starch Facts," p. 121.)

Another yeast completes the picture. Some 30 years ago, French scientists found what they called a "remarkable" yeast in tanning liquor derived from the wood of chestnut trees. They sent a sample to Peoria. It was *Pachysolen tannophilus*, a yeast like no other with a thick-walled tube that grows from a vegetative cell. The walls refract light and glow under a light microscope, making *Pachysolen* unusually easy to identify. Years later, in the 1980's, researchers found that the yeast can ferment xylose into ethanol, or ethyl alcohol. There is reason to hope that these two yeasts will enable industry to make alcohol and other products from mountains of unused crop residues.

Other NRRC researchers are using yeasts to produce organic acids and to break down fats. After screening 175 strains of yeast, scientists also pinpointed 4 that provide control of fungal decay in stored apples and pears. And a recent study showed that *A. pullulans*, the yeast that can break down xylan in plant fiber, contains an enzyme that may also be useful in processing fruit juices and in treating wood pulp to make fibers for paper and rayon.

Coloring certain foods to make them more appetizing—and perhaps more healthful—may also be possible with yeast. Many foods owe their natural color to the presence of carotenoid pigments, harmless substances that improve the color of foods such as salmon, shellfish, and sea trout. One pigmented yeast, for example, *Phaffia rhodozyma*, can synthesize a carotenoid that imparts a red color to the flesh of trout. There is considerable commercial interest today in the use of such pigments in animal feeds and food dyes. Carotenoids are not only safe, but some of them, including beta-carotene, are thought to inhibit the growth of certain types of cancer cells.

Enzymes in bacteria have also been put to work in the Northern lab. One bacterium found in the culture collection, *Aerobacter aerogenes*, produces a useful chemical called BHPA from glycerol, or glycerine. BHPA, which stands for beta-hydroxypropionic acid, is easily converted to acrylic acid, presently made from petrochemicals and used in acrylic fabrics, carpets, upholstery, and a long list of other products.

Another bacterium, *Clostridium thermoaceticus*, yields 45 percent more acetic acid from corn sugar than does the conventional vinegar fermentation process. Acetic acid is the expensive part of a compound called CMA, or calcium magnesium acetate. Nonpolluting CMA is an effective de-icer at lower temperatures than salt and will not corrode metal. The chemical is recommended by the Federal Highway Administration as an alternative to rock salt as a highway de-icer. NRRC researchers hope to bring down the cost of CMA until it is more nearly competitive in price with salt, which annually causes more than $5 billion in damage to roads, bridges, and vehicles.

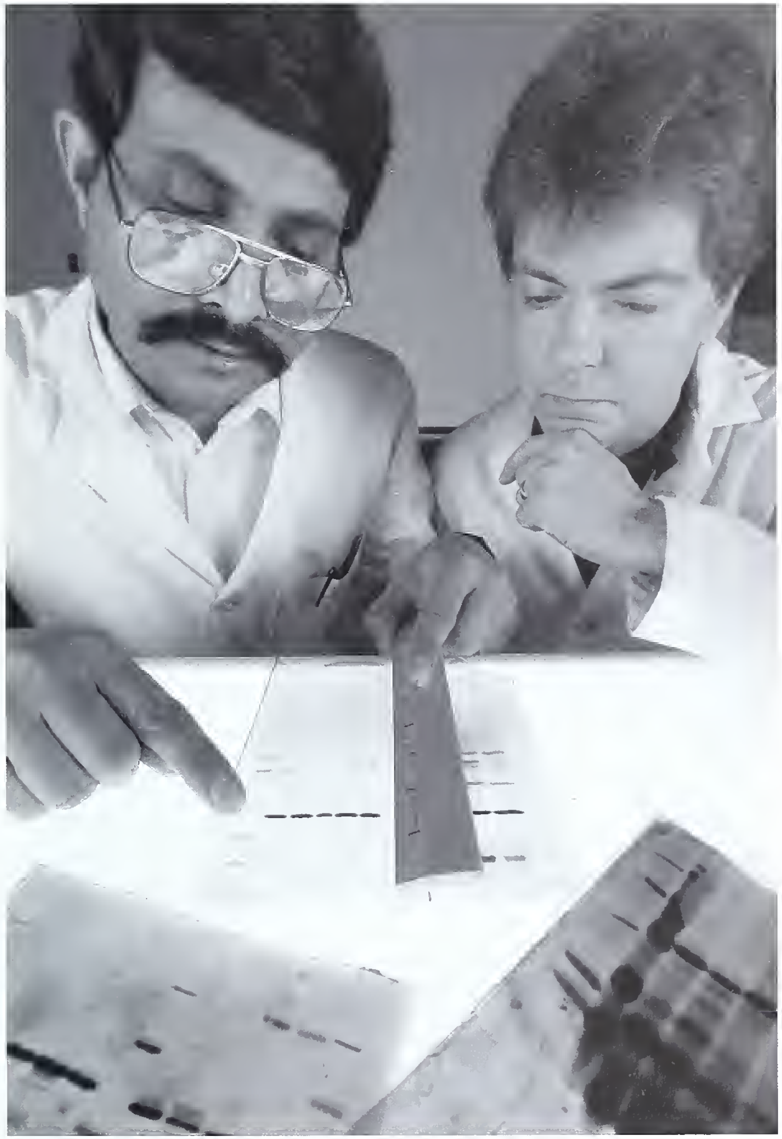
Crop Pest Control

The four regional laboratories did not become seriously involved with controlling weed and insect pests until the 1970's, when diminishing surpluses led to partial redirection of ARS research. Since then, pest control research conducted at many different ARS locations has been augmented by the talents and expertise of the agency's regional lab scientists. One pointed out that "perhaps our biggest surplus in this country is our endless supply of crop pests."

His comment may have been tongue-in-cheek, but he was dead right about the size of the crop pest army. Competing for our food and fiber are 10,000 species of insects, 1,800 weeds, 1,500 kinds of nematodes, and 1,500 plant and animal diseases. If we didn't control them, they would destroy from 30 to 50 percent of our crops every year.

Phytoalexins: A Plant's Defenses

Plants, like humans, possess chemical defenses to protect them from microbial infections. In a plant, an infection may cause what plant physiologists call a hypersensitive response. Such a response may trigger the production of chemicals called phytoalexins to fight the microbial infection. The fact that plants produce phytoalexins only when stressed is evidence that the chemicals are part of the plant's chemical defense mechanism. NRRC researchers are presently using a battery of modern techniques, including computer-based molecular modeling, to determine whether phytoalexins might have potential uses in agriculture or medicine.



Microbiologist Subhash Gupta (left) and geneticist Timothy Leathers look at data on purified fungal enzymes that may control certain insect pests of vegetables. The Peoria researchers are studying fungi that secrete enzymes that break down an insect's outer "skin," allowing them to penetrate it and consume the pest.

Fungus vs. Fungus

A beneficial fungus was approved in 1990 by the Environmental Protection Agency as a new biological control to fight two fungal plant diseases in greenhouses. The good fungus, a strain of *Gliocladium virens*, is able to reduce by 80 to 95 percent the plant losses caused by the two diseases, which presently cost growers more than $1 billion a year. Greenhouse owners refer to the diseases as damping off. They rot seeds, seedlings, and cuttings. Almost any seedling is vulnerable to attack, and victims include geraniums, snapdragons, chrysanthemums, poinsettias, celosia, cotton, corn, beans, and soybeans. The two bad fungi can destroy 10-30 percent of a crop.

Gliocladium, the good fungus, was isolated from local soil at an ARS laboratory in Beltsville, Maryland. Its dormant spores have been put into pellets, along with wheat bran and alginate—a natural gel-like material that binds the particles together. When the pellets are moistened, the spores germinate and the fungus multiplies and controls the diseases. The alginate pellet formulation was originally developed at the Southern lab. ARS has granted a company an exclusive right to produce the new product, which should be on the market shortly.

WRRC chemists Leonard Jurd and Rosalind Y. Wong examine a molecular model of a naturally occurring larvicide derived from a species of Panamanian tree. The chemical is highly toxic to termites and marine borers.

The female Mediterranean fruit fly is attracted by the aroma of ripe fruit but repelled by the scent of unripe fruit. Western lab chemists hope to synthesize the unripe fruit odor and use it to keep the pest away from ripening fruit.

In the first two decades after World War II, the farmer's favorite method for controlling weeds and insects was to poison them with chemical pesticides. That was usually the most effective and least expensive way to do it. But things went wrong with that approach. Pesticides killed beneficial insects as well as harmful ones. Wind sometimes blew them onto the wrong crops. Some, including persistent chemicals like DDT, concentrated in the food chain. And many insect and weed species grew resistant or even immune to specific pesticides. When that happened, it took new and more potent chemicals to kill them—or bigger doses of the old ones.

As a result of growing disenchantment with wholesale poisoning of crop pests, ARS and other research groups put more and more emphasis on finding biological pest controls. And in those cases where pesticides seemed the only answer, researchers have sought ways to use smaller amounts of poison and to pinpoint delivery to the specific weed or insect under attack.

One way that crop pests can be controlled without poisons is with fungi and fungal derivatives. Researchers in the Northern lab recently discovered a method by which five strains of fungi can be used to kill insects selectively that attack corn, wheat, and other crops. Each fungus secretes enzymes that break down the chitin that forms an insect's exoskeleton, allowing the fungus to penetrate and consume the pest. The researchers plan to isolate the most promising enzymes, using genetic engineering. The aim is commercial production of fungi that can be sprayed on crops. "The great thing about these fungi," says one scientist, "is that they are safe for plants, beneficial insects, people, and the environment. And it's unlikely that insects can develop resistance." These and other biological controls for pests require regulatory approval from the U.S. Environmental Protection Agency.

With our present knowledge, it appears that farmers will have to continue to make careful and sensible use of some chemical pesticides to control weed and insect pests of many crops. Two regional laboratories have invented ways to release such chemicals slowly and at minimum risk to the environment. One method, developed at the Southern lab, mixes a herbicide with a solution of algin, derived from seaweed. Droplets of the mixture are allowed to fall into a gelling solution. Slow-release gel beads form almost at once. The rate at which the herbicide is ultimately released in the field can be slowed even more by drying the beads in small pellets. The algin beads can also be used to encapsulate living biological control agents like fungi to kill weeds that spread crop disease.

Another SRRC process, similar to that used to make pasta, traps fungi or nematodes in granules of wheat dough. Weed-killing fungi grow to cover the granule surface and spread spores that infect and kill weeds. Entrapped nematodes escape when the granules are wet to kill harmful insects in the soil.

Peoria researchers have also encapsulated pesticides, but theirs are contained in a starch matrix. Controlled release reduces losses of pesticides from evaporation. Also, less of a chemical leaches into the soil during rainstorms, and it is protected from decomposition by sunlight. The pesticide in its starch jacket stays where it is targeted.

Bacteria and viruses that kill insect pests are also ideal candidates for starch encapsulation. Live pathogens die quickly in the field and must be protected if they are to be effective control agents. Recently, a Peoria team of scientists found that combining sugar with the starch in an encapsulated spray formula dramatically increased the length of time the formula stays in place to do its work. In one test, the sugar-starch spray adhered to plant foliage for up to 19 days, while formulations without the sugar flaked or peeled off in 2 to 4 days. In another test, the sugar-starch formula greatly increased the killing power of *Bacillus thuringiensis* (Bt), a biological insecticide. The inventors have entered into a cooperative research agreement with a private firm to test the formulation further. They hope to increase the spray's effectiveness while reducing the cost of producing it. (See chapter on "Corn and Wheat Starch," p. 120.)

Searching for Contraband

Day and night, agricultural inspectors at U.S. international airports must check the luggage of incoming passengers for fruits, vegetables, and other plant materials and for certain unprocessed foods. A foreign orange, for example, could contain larvae of the medfly, a costly enemy of citrus. A salami could harbor the organisms of rinderpest or foot-and-mouth disease and trigger a plague that could decimate America's livestock industry. Bringing such products into this country is illegal, of course, but that doesn't stop countless travelers from trying to do it.

WRRC's T. F. Schatzki (right) and Richard Young compare stored TV image of suitcase items with actual contents. The suitcase was opened after it emerged from X-ray scanner. Schatzki is seeking a way to detect contraband without opening every piece of luggage.

To help USDA inspectors with their difficult task, researchers at two regional laboratories have come up with two different systems for screening incoming luggage. One method sniffs; the other looks. Both have been tested successfully at U.S. airports.

A hand-held infrared sniffer gun, developed at the Eastern lab, activates a warning light when it detects high levels of carbon dioxide in a box or suitcase. Fruits and vegetables give off the gas once they have been picked. The sniffer was first tested by inspectors at Los Angeles International Airport to screen luggage of visitors to the 1984 Olympics.

Another experimental method, this one developed at the Western lab, uses X-ray, video, and computer technology to spot suspicious-looking luggage before it gets to the inspector. As a bag is unloaded from a plane, an X-ray picture of what's inside is fed to a computer. The computer, which has been programmed to spot suspicious food shapes, analyzes the bag's contents and stores the information. At the same time, the X-ray image of the bag is displayed on a TV screen, where a brightly colored outline instantly highlights any food shapes recognized by the computer. The X-ray and video can scan bags at the rate of one every 3 seconds.

If the automated system identifies a food shape, the suspect suitcase is coded, alerting inspectors that the luggage should be searched after the traveler picks it up. Inspectors can call up X-ray images of bags being searched so that they will know where to look for suspect contraband. When tested at San Francisco International Airport, the WRRC system spotted such illegal items as coconuts, oranges, fresh mangoes hidden in large tin cans, and partially cooked duck eggs. Their shapes gave them away.

Chemist Gregory M. Glenn at the Western lab studies a 3-D computer model of a grain of wheat in research project to coax more flour from each kernel.

Computers for Research

It is safe to say that every scientist today uses computers in some way to carry out research. Typically, the Northern center has a central scientific data processor to serve needs of the whole laboratory. It is used to collect raw data, perform mathematical analyses, augment instruments, produce reports, and store the data. It is an indispensable research assistant.

On some projects, however, the computer is more than that. A scientist at the Southern center, for example, insists that the computer is his "primary research instrument." It enables him, he says, to predict the physical shape of large molecules, often with minimal experimental data.

It is not enough for a chemist to know the kinds and numbers of atoms in many organic molecules, such as starch or cellulose. The physical properties of compounds also depend on the shape and configuration of the molecules. It is often difficult, however, to determine three-dimensional structures of many giant molecules through laboratory experiments.

The SRRC modeling project has already resulted in the first precise description of the double-helix shape of a starch molecule, a structure now generally accepted by the scientific world. A current project seeks to determine the energies of different shapes of sugar rings, based on research conducted by an SRRC scientist in the pre-computer days of the 1940's. At that time, he worked out on paper all the possible shapes of sugar rings. Today's computer research is an outgrowth of those pioneering studies more than 40 years ago.

Comparable modeling with computers is taking place at the Northern center. Under study are long molecules of triglycerides, fatty acids, and lipids that contain large proportions of carbon and hydrogen. Some of these compounds are essential to life; others are harmful if ingested but essential for many home, automotive, and industrial uses. Unsaturated fats are good for dietary purposes, for instance; saturated fats, not so good.

Fat molecules are able to perform many different tasks because they contain long chains of carbon atoms that tend to associate with each other and form larger molecular aggregates, each with different properties. Because of their chemical structures, chains of carbon atoms in saturated fats tend to be straight, while those in unsaturated fats are bent. Fat molecules can also take on different shapes and dimensions that can change with ease, depending on the conditions under which the fat is used. This ability to assume many different forms makes fats useful, but it can complicate fitting the fat to the task. With modern computer software and knowledge of the specific properties that are required of a fat molecule, chemists can build molecules atom by atom, move them around, and change their shape. Finally, they can determine whether the molecule's shape and packing will provide the properties needed for a particular task. Soon chemists will be able to identify the best fat molecule for each purpose, whether for the human diet or for industry.

At the Western center, three-dimensional computer modeling is a powerful tool to help researchers improve their understanding of milling wheat. Wheat flour is made by stripping away the outer bran layer of wheat kernels and crushing the endosperm, the inner tissue that produces the flour. About 8 percent of the endosperm remains stuck to the bran and is lost during milling. If more of the endosperm could be separated from the bran, it would mean a tremendous increase in flour production.

Just as a 3-D computer model can help pinpoint where an engine is most likely to fail, it can also predict how a kernel of wheat will respond to various preconditioning and crushing treatments. Western center scientists are confident that computer modeling will eventually enable millers to fine-tune their milling practices to achieve higher yields of flour.

The Eastern center has come up with a different sort of computer program. Faced with higher energy costs, more stringent environmental rules, and requirements for nutritional labeling, managers of food processing plants are more concerned than ever with increasing the efficiency of their operations. To help them do this, ERRC researchers have created a computer program and models applicable to many different types of industrial activity. Called the ERRC Food Process Simulator, it was designed to help processors achieve not only higher production and profits, but also a more nutritious product made in a more energy-efficient manner. The program can be used to make theoretical changes in a production process on a computer without the cost and disruption of actually making the physical alterations in the plant. It can be applied to parts of a process as well as to the whole production system. Since the ERRC program and models were developed, more than 100 organizations have obtained copies and are modeling industrial processes for such diverse commodities as potatoes, crackers, cheese, beer, corn, chocolate, and pharmaceuticals.

In another Eastern lab unit, scientists had for many years studied the proteins in casein (from milk) and collagen (from hides) to improve their function and utilization. While a great deal of physical chemistry data had been collected on these proteins, the exact molecular structure remained elusive until the computer came along. Today ERRC researchers construct theoretical 3-D models of these noncrystalline proteins in the computer, based on the amino acid sequence. They then adjust the models to incorporate known physico-chemical details. The computer simulation usually suggests further experiments to verify each model, and the new data are used to refine it even more. Molecular models help researchers to predict, among other things, the optimal conditions for processing the proteins into useful products. They also help scientists to understand how each protein functions in the animal's body.

Basic Research

One way to tell the difference between applied research and basic research is to listen to the questions a scientist asks. In conducting applied research, the questions are apt to be: How can we use this stuff? Is there the potential for a new product here? Is there a better way to process this? A faster way? A cheaper way? A safer way? How do we get the bugs out of this invention? How can be make this last longer? Or taste better? Or bounce higher? Or smell sweeter? Like Edison working on the incandescent light bulb, men or women conducting applied research can tell you what they are trying to do.

Basic research questions sound much less specific: What's happening here? Why is it happening? Does it have to happen this way? What on earth is this stuff? What's it made of? How is it put together? How does it behave? What are its properties? Ask basic researchers what they are up to, and they will often reply, with more than a hint of impatience, "We're just trying to find out something about this thing." Or, to put it another way, a researcher on an applied science project is trying to develop a product or a process. A basic researcher is seeking general knowledge.

Even practical-minded industry people frequently call for more, not less, basic research. A Cotton Advisory Committee of cotton farmers and textile industry people was formed in 1948 to recommend needed research to the Southern center. The Committee soon identified 82 priority projects; 28 of them called for new or improved cotton products, and 10 sought better cotton processing machinery. But 25 dealt with fundamental research on the nature and properties of cotton fibers. One of the early directors of the New Orleans lab recalled that in following up on

In the Western center, plant physiologist Sui-Shang Hua removes a bit of hairy carrot roots for propagation in fresh medium. She is studying the influence of host plant roots on development of endomycorrhizal fungi.

these recommendations, his group used techniques like X-ray diffraction "to explore the invisible inner structure of cotton fiber."

Knowledge so obtained, he wrote, "is the foundation for research that eventually leads to more practical developments." He explained, for example, how studies of fiber properties revealed that certain types of cotton, when spun into yarn or woven into cloth, prevent the passage of water better than others. This basic finding led eventually to development at SRRC of water-resistant cotton fabric.

Since 1940, researchers at each of the regional centers have become known and respected by scientists throughout the world for the significance of their basic research. Among these men and women were a succession of brilliant chemists at the ERRC lab who isolated milk proteins and described their properties. And there was the Eastern lab team that found a new method for determining the arrangement of carbon atoms in sugar.

Researchers in Peoria developed the Culture Collection of microorganisms, defining species on the basis of the relatedness of their DNA. Another NRRC team expanded the world's understanding of aflatoxins at a time when little was known of these carcinogens. In the West, a team worked out the chemistry of the pectin enzymes polygalacturonase and methyl esterase with research described by other scientists as "classical." Western researchers also did innovative work in exploring the intricate chemistry of flavors and aromas.

In the South, scientists more than 40 years ago originated conformational analysis and determined the shape of pyranoside rings in simple sugars, opening the door to much subsequent research. In all four centers, scientists practically wrote the book on proteins and the chemistry of fats and oils. (Center scientists, in fact, did write many books on these subjects and two edited the major handbook on industrial fats and oils.)

It has been demonstrated many times that scientists have to have answers (either their own or somebody else's) to fundamental questions before they can find answers to the practical ones. But—and this is a very big "but"—the men and women who administer ARS research feel strongly that even fundamental research should be conducted in directions that appear to lead—at least in a general way—toward solution of a problem or exploitation of an opportunity. It is always a difficult decision for a research administrator to transfer research assets and people from a project with an unclear purpose to one that appears more promising, but it occasionally becomes necessary.

Following are several examples of fundamental research conducted at the regional laboratories in the 1980's, along with some of the possibilities for practical use of the knowledge obtained:

A WRRC scientist asks: How is it that barley, among all the grains, can tolerate salty soil? This is an extremely important question. Soil salinity is accelerating at an alarming rate here and in many other countries, and even moderate levels of salt lower yields of most other crops. So far, Western researchers have identified two different responses to salt stress in barley plants. One is an increase of a specific protein in barley roots; the other is increased activity of ion pumps in barley membranes. At this point, the researcher simply wants to understand the complex processes that occur when barley is stressed by salt. Objective: If he can discover the molecular basis for salt tolerance in this one grain, it's possible that the knowledge will help to breed other crops, including wheat, with similar tolerance.

Another WRRC researcher removes tomato flowers from plants and grows them into fruit in culture tubes. This procedure allows her to control the amounts of nutrients and hormones supplied to a plant tissue or organ. She also controls temperature, length of daylight, and acidity. So far, she discovered the existence of an enzyme that triggers ripening of the fruit and is trying to isolate it. Eventual aim: Tomatoes grown for processing that ripen all at once; or the reverse—tomatoes that stretch out ripening over a longer season for fresh market sales.

At the Eastern lab, scientists developed a "nitrogen bomb technique" to isolate functionally active cell walls from plants. The method has allowed them to identify which enzymes in the cell walls are part of the plant's defense system. It also revealed the structural location of a key cell-wall component. Eventual aim: Many potatoes and other crops are lost to microbial attack during storage. Understanding how these pathogens invade plants and how the plants defend themselves is necessary, researchers believe, to help breeders develop disease-resistant crops.

An NRRC biochemist, in cooperation with a former colleague who has moved to Michigan State University, has created a synthetic gene that carries the blueprint for a key protein needed for oilseed plants to produce oil. Using a new instrument called a DNA synthesizer, he constructed the gene from 16 DNA fragments called nucleotides. He used enzymes to link the fragments together. Possible application: Genetically engineered oilseed crops that produce more or healthier oils.

Researchers in the West have developed probes to aid in the study of a hormone called cytokinin that may hold the key to slowing down the natural aging of plants. Longer life would give plants like wheat a little extra time to pack more nutrients into each kernel. Also under study are *mycorrhizae,* friendly fungi that perform a long list of useful chores for crops. Living on plant roots, the fungi send out finely branched, threadlike hyphae that act as miniature pipelines for nutrients. They bind particles together in erosion-prone soils, help plants survive in soils high in toxic metals, and keep crops alive during drought by extracting moisture from soil pores. They also shuttle phosphorus, zinc, and copper from the soil to host plants, reducing the need for phosphorus applications by the farmer. Aim: To find the most effective *mycorrhizae* strains and to understand how they perform their many functions.

Admittedly, this is but a sample of the scores of basic research projects now being explored in the regional laboratories. In terms of practical results, of marketable products, some of the projects can be expected to end in failure. But it is impossible to know in the early stages of research where fundamental questions will lead. One thing is certain: There will be no scientific progress without the knowledge gained through basic research. How much to invest in such work, and in which areas, is a matter for research administrators to determine after consultation with scientists interested in the projects.

The mystery of barley's ability to grow in saline soils is under study by a WRRC researcher, who hopes to use knowledge to make other grains salt-tolerant.

Cotton Research Today . . . and Tomorrow

The farm value of cotton grown in the United States today is about $4 billion a year, placing it among the Nation's top six field crops. Its worth is multiplied many times beyond its crop value when it goes into textiles, apparel, and industrial products. But while cotton continues to be big business in this country, it will take continuing and aggressive research to keep it that way. For American cotton today faces competition, not only from synthetic fibers, but also from cotton grown in foreign countries. Worldwide, cotton production is on the increase. To survive, U.S. cotton must be the world's quality cotton, produced at a cost competitive with synthetics and large-volume foreign cotton producers.

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The Agricultural Research Service is engaged in several research programs aimed at helping cotton maintain and improve its competitive position. One approach is to improve cotton production and ginning. Another is to improve cotton fiber by finding ways to produce cleaner, stronger cotton with longer fiber staple length and greater uniformity.

To help the processor lower costs, ARS is developing technology to produce higher turnout in ginning and is seeking new ways to cut costs in spinning and dyeing. It is taking a look at the whole farm-to-consumer system for cotton to see if that system can't be made more efficient. Finally, ARS researchers, and those at the New Orleans laboratory in particular, are exploring new ways to modify cotton fabrics chemically to develop 100-percent cotton products that are durable, dyefast, and permanently pressed, while still retaining cotton's attractive feel and comfort. They are also seeking better methods for imparting easy-care properties to cotton fabrics while increasing their wear life. Another goal is quick-response technology that will render easy-care cottons dyeable after a garment is manufactured.

Recent laboratory tests at SRRC have demonstrated that the lab's new no-formaldehyde process for making wash-and-wear fabrics from 100-percent cotton is not only safer for textile mill workers but also results in fabrics with much improved durable-press properties. Work is continuing to move this important research from the New Orleans laboratory to commercial application.

To increase U.S. chances for achieving needed improvements in fiber strength, length, and other desirable properties, ARS has established a national cotton-quality program. Improvement starts with measuring the variables that the grower will be paid for. ARS labs at New Orleans and Clemson, South Carolina, are working on high-speed methods for measuring trash, short fiber content, and fiber maturity. Other specific research goals assigned to the Southern laboratory include:

- Finding out more about the basic molecular mechanism that controls the growth of the cotton plant and that of the fiber.
- Carrying out investigations of the structure of cotton fiber.
- Conducting background research to improve quality and cost of processing cotton fiber in ginning and in the textile plant.
- Improving finishing of cotton and cotton-blend fabrics.
- Developing better methods for monitoring small quantities of formaldehyde in the workplace.

SRRC cotton technologist A. Paul Sawheny checks on patented new system to blend more cotton fiber with synthetic fibers to make fabrics that combine strength of synthetics with comfort and breathability of 100-percent cotton.

- Imparting flat drying properties to cotton fabrics that do not contain formaldehyde.

These and other projects are carried out in New Orleans by specialized teams of scientists. One focuses on improving the all-important properties of fiber strength and length. While strength and length are measured for every bale of cotton, scientists still know too little about how cotton fiber growth determines fiber chemistry and the fiber's physical properties. The research team is investigating these relationships with many modern analytical tools. So far, it has made several basic discoveries, including the carbohydrate composition of the growing fiber and the biochemical changes that occur during fiber growth.

Another team is studying the effects of stress on cotton plants. It identifies changes in the cotton fiber molecules that result from adverse weather, such as a freeze or drought. The team has learned that the molecular structure of the cotton fiber influences its strength and therefore its quality. These basic findings will help farmers produce higher quality cotton for processing and eventually mean longer product wear-life for the consumer.

One scientific group in New Orleans uses highly sophisticated equipment to determine the pore structure of cotton. Cotton's porosity is directly related to its ability to take up dye. For the first time, SRRC scientists are learning the impact of various processing treatments, like scouring, bleaching, and mercerization, on the size of cotton pores and therefore on the cotton's accessibility to chemical agents and dyes.

Focus on the Future

"The more things change," the French saying goes, "the more they remain the same." In several ways, that summarizes the history of the ARS regional research centers. So much has happened during the last 50 years: a rapidly increasing world population despite war, famine, and natural disasters; growing worldwide environmental concern; an explosion of scientific information; new technologies, including the invention of atomic weapons and atomic power; biotechnology and genetic engineering; the silicon chip and the modern computer; and hundreds of other innovations that have changed the lives of everyone on this planet.

But much is still familiar; many of the challenges that confront researchers today bear a striking resemblance to those of 50 years ago. When the regional laboratories began, they were charged with finding new uses and markets for surplus agricultural commodities to help improve farm income. Developing new products from surpluses is still a primary mission today. Fifty years ago, many people in the world went to bed hungry; tragically, even more people, including millions of children, are hungry and malnourished today. Many of the old threats to humankind's health and safety are still with us—and still dangerous—and new maladies sicken and kill uncounted millions. Environmental hazards, like floods, soil erosion, and agricultural wastes, were major concerns in the United States in the 1930's and 1940's; erosion and waste disposal and water management confront us in the 1990's, and with even greater urgency than in the past. Helping find answers to these and other problems through research continues after half a century to be the mission of ARS scientists in the regional centers.

The four original laboratories, along with the newer Richard B. Russell Agricultural Research Center in Athens, Georgia, recently completed a thorough reappraisal of their objectives. In several instances, they have been reorganized to strengthen their research programs, responding to needs of farmers and ranchers, processors and manufacturers, and consumers. They have also embarked on a much needed modernization of their physical plants to help them meet revised research goals.

> *"A technological revolution is taking place in the food industry primed by changing consumer demands involving health, convenience, and even luxury . . ."*
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> *. . . R.D. Plowman, Administrator, ARS*

Receiving renewed emphasis at the centers is the development of more value-added products derived from agricultural commodities. In a Senate directive accompanying the FY 1990 appropriation for the Department of Agriculture, the Congress called on USDA to "make substantial progress" in moving toward an annual program level of at least $50 million to finance "research on new nonfood uses for traditional food commodities such as wheat, corn and soybeans..." The amendment observed that such a program "should help ensure a better balance between production and utilization research as well as higher prices for farmers, expanded international trade opportunities, and smaller Federal outlays for farm programs."

Congress is aware that many of the raw fruits, vegetables, grains, and dairy products exported by the United States for comparatively low prices are returned to this country as specialty foods and ingredients and pharmaceuticals. These are often sold to us at considerably higher prices than we received for the farm commodities from which they were derived. The development and production of more value-added agricultural products at home would bolster farm income and improve America's international trade balance. A related aim is to lessen U.S. dependence on foreign imports of strategic materials, such as natural rubber and petroleum.

The research plans of ARS program managers had called for more new product research at the utilization centers even before the Congressional directive made its appearance. Another continuing goal for the centers is the improvement of food and fiber products to make them more attractive to U.S. consumers as well as to foreign purchasers. As ARS Administrator R. D. Plowman said in remarks at ERRC's 50th anniversary open house, "A technological revolution is taking place in the food industry primed by changing consumer demands involving health, convenience, and even luxury. Consumers want products that are safe, nutritious, fresh-tasting, microwavable, and free from chemical additives. That translates into new opportunities, not only for the domestic market, but also overseas." Another

An important objective of the four regional research centers is the development of more value-added products from agricultural commodities. Many of the commercial items contain ingredients that are the result of ARS utilization research.

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objective of center research is to contribute to a more healthful, productive environment and a sustainable agriculture.

Projects in support of these goals are currently being conducted at all the regional laboratories, and many of them respond to two or more objectives. In Peoria, for example, researchers are developing new chemical specialties from soybean oil.
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Partially soy-based inks, alternatives to conventional petroleum-based inks, had already been developed by the American Newspaper Publishers Association. In 1987, the *Cedar Rapids Gazette*, an Iowa paper, did a press run with these inks. The test was so successful that the paper decided to convert completely to partial soy-based colored inks.

However, the black soy inks didn't enjoy popularity with printers. Not only did the ink tend to rub off the printed page, but it was harder to clean the presses after a run.

Chemists at the Northern lab, at the behest of the newspaper publishers and the American Soybean Association, joined the effort to develop a 100-percent soybean oil newspaper ink. They successfully formulated inks in the four colors commonly used in newspaper printing: black, blue, red, and yellow. These inks are adjustable to a wide range of viscosity and tackiness for news offset printing. They're competitive to petroleum inks in cost, with rub-off characteristics equal to those formulated and marketed as low-rub inks.

In other Peoria new-product research, work continues to develop plastic mulches, films, and injection-molded plastics that incorporate starch in their formulations and that will biodegrade above or below the soil. Such new products would make use of surplus corn and help with solid waste disposal. Also, the use of starch-encapsulated pesticides, another Peoria invention, cuts down on air and water pollution by reducing the application rate of herbicides and insecticides. In recognition of the Northern laboratory's successful value-added product research and its large number of patents and licensing agreements, the Congress on December 28, 1990, renamed it the National Center for Agricultural Utilization Research (NCAUR).

At the Western laboratory, a major goal is the production of natural rubber from bioreactor systems that use large quantities of cereal starch as a fermentation medium. The goal is to transfer genes from *Hevea*, the natural rubber tree, to a microorganism and then to use the microbe to produce rubber through fermentation. This is but one of several research projects at regional laboratories that seek to make use of fermentation systems to produce, not only rubber, but improved detergents, bioemulsions, organic acids, and anti-settling agents.

Other WRRC research seeks to transfer insect resistance from one species of plant to another and searches for ways to make crops more salt-tolerant. Another project looks for safer and more effective ways to eradicate the medfly with new approaches to biocontrol, and yet another would protect lightly processed fruits and vegetables with edible coatings.

In the South, researchers are working to develop innovative products from surplus tallow, butterfat, soybean oils, nonfat dry milk, and rice. Among other things, they are developing a brown rice with a shelf life two to three times that of today's product. New Orleans scientists are also learning more about how desirable and undesirable flavors are formed in foods, and they are looking for added-value products from surplus crops that can remove toxic wastes from industrial wastewater.

Redirected programs at the Eastern laboratory include making castor-oil-like products from animal fats. All of America's castor oil requirements are currently imported. ERRC scientists are also working to produce metal-chelating agents from carbohydrates and preparing polymers from pectin for use in biodegradable plastics or in medicine. Also under investigation are new uses for food stabilizers made by combining pectins with proteins.

To meet growing consumer demand for food ingredients perceived as being safe, convenient, natural, and health-promoting, Eastern lab scientists are conducting promising research on fermentation systems to develop "natural" flavors from the action of fungi on butter. They are also working on improved computer models for predicting the growth and survival characteristics of foodborne pathogenic bacteria.

This is but a sampling of the exciting research projects now under way at the utilization laboratories. In what could well be a statement on behalf of all the centers, the Eastern laboratory, in concluding a 50th anniversary brochure, stated recently: "Thus as [we begin] the decade of the 90's...much of our research has returned to that for which the four regional centers were originally established—utilization research." To confront this challenge, the centers today have clear goals and experienced leadership, modern research facilities and equipment, improved mechanisms for technology transfer, and scientists with the education, experience, and enthusiasm to make their second half century even more productive than the first.

Sevim Erhan, a chemist in the Peoria center, prepares black and color newsprint inks made from 100-percent soybean oil for printing tests in the laboratory.