NORTHEAST REGIONAL RESEARCH PROJECT

PROJECT NUMBER:  NE-179 (Revised)

TITLE: Technology and Principles for Assessing and Retaining Postharvest Quality of Fruits and Vegetables

DURATION:  October 1, 1997 through September 30, 2002

STATEMENT OF THE PROBLEM:

The problem of assessing and maintaining the quality of fruits and vegetables limit the profitability and competitiveness of the United States fruits and vegetable producers and processors. Fruits and vegetables are subject to damage during harvesting, handling, and shipping if not handled properly. The ability to assess and quantify properties pertinent to damage is important in preventing and reducing damage and for selection of cultivars. Soft fruit is the most frequently reported physiological disorder on USDA receiving inspection forms. It is not totally clear which physical and biochemical properties affect firmness. A common approach to minimizing variability is to separate the produce into groups according to firmness. Various non-destructive firmness sensing methods have been proposed. However, they are still in the developmental stage and need further work before they can be employed commercially.

Significant progress has been made towards developing sensors to measure both the external and internal quality parameters. However, development of sensors into real time grading lines and inspection stations is the next challenge. Much of the previous work with sensors has been under static conditions and there is still more work that remains. The dynamic conditions of on-line systems introduce new conditions and speed requirements that are not inherent in the static tests. Integration of sensors into a practical, portable inspection station that can operate at the speed desired by the industry requires improvements and adaptations of modern technology.

Fruit and vegetable quality determination can be enhanced by employing modern sensing techniques. These techniques are different from classical sensing techniques in that the information is determined from signal patterns as opposed to a single signal value. Furthermore, information may be determined across multiple sensors as opposed to an isolated single sensor value. Multiple inputs entail the need for careful consideration of the signal processing step as an integral part of sensor system design. The advent of fuzzy logic approaches, the neural networks, and other advanced classifying techniques enable rapid and
economical on-line implementation. The benefits of using multiple inputs are significant considering the economic premiums that are placed on consistent, superior quality in the marketplace.

JUSTIFICATION:

The fruit and vegetable industry in the United States generates over $6 billion in income annually. Domestic and foreign consumers crave and demand quality in both fresh and processed fruits and vegetables. The produce industry in the United States is competing in a world market that makes the industry vulnerable to high quality imports. Our foreign competitors have better quality control, marketing strategies, and lower labor costs that often allow them to deliver higher quality fruits and vegetables to the United States. We must develop and incorporate the best and most effective technology so the U.S. produce industry can compete globally and expand U.S. export markets especially to countries such as Japan.

Consumers are becoming more health-conscious and aware of the importance of fruits and vegetables in their diet for enhanced nutrition. Consumers are demanding consistency in maturity, textural quality, nutritional quality, food safety, freedom from bruises and damage, appearance, freshness in addition to an increasing variety of products. Unless high and consistent quality of fruits and vegetables is provided, consumers are less likely to purchase these products which would result in a loss in sales of fruits and vegetables and in nutritional quality for the consuming public.

Methods currently available for detecting quality are ineffective. Relationships between the quality attributes and the handling methods are not clearly understood. There is a fundamental lack of understanding of the underlying physical, chemical, and biological characteristics of fruits and vegetables that can be detected by existing and proposed sensors. Research is underway to gain an understand of the underlying phenomena influencing quality essential to the development of the sensors. Furthermore, research efforts must continue to determine the effect of different handling techniques on quality degradation.

A cooperative regional project is an excellent vehicle for the proposed research effort. Some of the instrumentation necessary to investigate the underlying phenomena influencing quality is sophisticated and expensive. It is not possible for one station to accumulate all the equipment and expertise necessary to carry out meaningful research. Fortunately, as a group, the cooperators in this project have access to most of the technology needed to assess quality. The cooperators will share equipment, experience, and ideas directed at common goal. Furthermore, there are cooperators that have similar equipment (machine vision and NMR) and can share data, software, and techniques. Lastly, some cooperators share
commodities and all cooperators share an interest in developing qualitative measures of quality.

The proposed project is consistent with the national needs and priorities. A good diet: America's best health plan is a priority listed under the heading of a safe, affordable, reliable, and nutritious food supply. The availability of consistent and high quality fruits and vegetables to the consumers will enhance consumption and improve nutritional value of consumers' diet. Another national priority is to improve the competitiveness of the U.S. food and natural resource system. By consistently providing high quality fruits and vegetables the American growers would be more competitive in domestic as well as foreign markets.

RELATED CURRENT AND PREVIOUS WORK:

A significant portion of the current effort related to the three objectives of this project is being conducted by members affiliated with this project with a few exceptions. Only current work is briefly summarized here. Please refer to the Critical Review included in the Attachment for a more complete discussion of previous work.

Firmness and bruise susceptibility, as indicators of quality, continue to be a focus of current research. Several methods of measuring firmness are being investigated (Chen et al 1995, Hung and Prussia, 1995, Timm et al, 1996). These include response to static and dynamic forces including impact. Contact pressure that causes cell failure is being investigated as a possible indicator of firmness and bruise susceptibility (Chowdhury et al, 1995). Finite element modeling technique is being used to simulate bruising due to quasi-static loading and resonant vibration as affected by material properties (Chowdhury, 1995). Bruise susceptibility of apples, potatoes, peaches, and onions is being measured using the instrumented sphere (Schulte et al, 1994, Timm et al 1991). Studies are underway to understand what specific properties are measured when measuring firmness. Another property being investigated is turgidity. Shock wave speed through tissue samples as a measure of relative turgor is being investigated. Effect of factors such as orchard site conditions, production practices and environmental conditions on changes in fruit physiology and chemistry of cherries are being investigated.

The potential of X-ray technology for inspecting internal quality is being evaluated (Tollner et al, 1995). Insect damage, fresh bruises, corky tissues and void spaces are detectable based on X-ray absorption patterns associated with these features. Preliminary results show that pits in stone fruits such as peaches can also be detected. X-ray computed tomography (CT) is being utilized to detect changes in tissue absorption properties while in storage precipitated by initial impact bruise.
Techniques and technology are being tested to determine if potential exist to electronically detect bruising and skin cracks on dark sweet cherries. Bruise detection using NIR and visual reflectance from the apple surface is being investigated to optimize lighting, lens aperture, and camera sensitivity for greatest contrast between bruised and unbruised tissue (Upchurch et al, 1994, Upchurch et al, 1993, Throop et al, 1994). Combining NIR and green reflectance features from images of Golden Delicious apples show promise as a way of detecting bruise tissues (Throop et al, 1992). Internal water core damage has been detected using transmitted visible and NIR light (Upchurch and Throop, 1991). Fluorescence is being studied as an indicator of respiratory activity (maturity).

Nuclear Magnetic Resonance (NMR) is being used to perform constituent analysis of fruits and vegetables, particularly, soluble solids and oil contents and maturity (Cho et al, 1993, Stroshine et al, 1994). NMR is also being studied to detect internal defects such as pitted and unpitted cherries.

Efforts are under way to develop software to analyze visible and NIR images and other multidimensional sensory data from fruits and vegetables. Fourier analysis, texture analysis and computed tomography have been areas of intense interest (Tao et. al. 1995a). Algorithms have been developed to form a basis for a single pass quality feature inspection and grading. Image analysis algorithms are being developed to assess and quantify color, shape, and russet (Heinemann et.al 1995a and Tao et. Al. 1995b). Relative strengths and weaknesses of artificial neural networks versus traditional statistical classifiers are being addressed. Performance of the back propagation neural network and the Fischer discriminant function are being studied for machine vision inspection of greening, shape, and shatter bruise in potatoes.

A survey is being conducted of the apple industry (packers and processors) to evaluate their current satisfaction with automated sorting and their future needs and tolerance expectations for automated sorting. The objective is to help the apple industry understand the state of current technology and to bring the development of automated sorting systems in line with the needs of the apple industry.

A search of the USDA Research (CRIS) data base was conducted to identify any other related research. Many of the research projects retrieved used existing fruit and vegetable quality measures to quantify the effects of breeding, fertilization, chemicals, handling, storage, cultural practices, or marketing, but, do not in any way duplicate the efforts of NE-179. The vast majority of retrieved projects were associated with participating stations.

Florida, Texas, New Jersey, and Oklahoma are reporting recent or current projects that are
related to the regional project in varying degrees. All of these stations have considered joining N E-179 and are aware of the goals of this regional project. In all cases N E-179 Regional project personnel are aware of, and do not duplicate, these efforts. T E X06500 is developing an adaptive sorting of carrots for size, shape, splits, and surface defects using commercially available optics. N J08903 is an inactive (and recently expired) project that was actually developed under the N E-179 Regional Project. O K L02178 was looking at sonic and impact measures to non-destructively quantify peach firmness. F L A-AGE-03087 has recently concluded a project to "design, test, and evaluate various handling systems to reduce mechanical damage and improve quality maintenance of fresh produce."
OBJECTIVES:

1. To identify, develop, and evaluate methodologies to assess the quality of fruits and vegetables.

2. To develop sensor technology for quantitative measurement of fruit and vegetable properties indicative of quality.

3. To develop methodologies for classification and sensor fusion which facilitate optimal fruit and vegetable quality discrimination.

PROCEDURE:

Executive Summary:

The quality definition of fruits and vegetables depends on the product and the manner in which it is consumed. The quality parameters include but are not limited to size, shape, weight, color, defects (external and internal), maturity, firmness, and bruise susceptibility. The three objectives describe a systematic approach for developing a system for on-line quality assessment and classification of fruits and vegetables. Under objective 1, attributes that may be used to define quality will be investigated as well as how these attributes can be measured. The on-line sensor development will be addressed under objective 2. Under objective 3 we will focus on the development of methodologies for sorting fruits and vegetables based on signals from multiple sensors that will utilize modern classification techniques such as neural network and fuzzy logic.

Objective 1: To identify, develop, and evaluate methodologies to assess the quality of fruits and vegetables.

A. Evaluate impact properties (bruise threshold and bruise resistance) of fruits and vegetables related to bruise susceptibility - an important quality parameter.

Currently different methods (e.g. dropping test or pendulum impactor) and protocols for measuring those impact properties are being used. The researchers will work together to identify common methods and procedures for measuring impact properties of fruits and vegetables. The susceptibility of fruits and vegetables to damage will be studied on peaches, apples, cherries, potatoes, sweet onions, and wild blueberries using the common methodologies developed for assessing impacts and damages. Information collected will be
related to maturity and cultivar. Specific recommendations on cultivar selection will be added to a common database and also made available to producers. (GA, ME, MI, ARS-MI, WA)

Cooperating stations (GA, ME, MI, ARS-MI, and WA on impact property; and GA, ME, MI, NC, ARS-MI on firmness) will develop standard procedures for quality evaluation, identify reference standards, and define what is being measured. Cross-correlation between different properties measured and quality will be conducted. A database encompassing all of the physical and chemical properties of all fruits and vegetables measured from this project will be established.

Cooperating stations (CA, GA, HI, MI, NY-C, PA, WA) will develop indices for basic product quality and quality consistency. Data from these stations will be compared to determine if the quality indices are applicable over a broad geographic region. Furthermore, this project provides an avenue for the cooperating stations to design future replicated experiments and compare the results.

B. Quantify fruit firmness, the most frequently reported physiological disorder recorded on USDA receiving inspection forms.

A common approach for minimizing variability and for marketing products with uniform firmness is to separate a batch of items into groups with similar firmness levels. There are a number of research projects, both completed and on-going, that have the objective of firmness sensing. Different firmness sensing methods such as Instron puncture, nondestructive force response, pressure sensing, and laser-puff will be compared. Firmness measurement will be made on fruit samples from a single source by researchers at different stations (CA, WA, GA, ARS-MI). Results will be compared and evaluated to determine the advantages and disadvantages of each system and ways to improve firmness measurements.

Fundamental research to identify which properties different devices are sensing, relative contributions of the skin and flesh to the readings, and how these readings relate to the firmness will be investigated. Design, fabrication and calibration plans of different firmness sensing methods will be shared among all cooperating stations. Results of these investigations will be used to form the basis for firmness sensing strategies for selected fruits (AR, GA, ME, MI, NC, ARS-MI). Several stations will emphasize the development of techniques to better predict maturity and shelf life of fruits and vegetables. Firmness is often used for estimating maturity of fruits and vegetables, however, non-destructive testing that compares well to current destructive test remains a challenge. Firmness measurements will be made on fruit samples from a single source by researchers at different stations (CA,
WA, GA, ARS-MI). Results will be compared and evaluated to determine the advantages and disadvantages of each system and ways to improve firmness measurement.

Equipment for measuring impact properties and firmness will be shared among cooperating stations. Design, fabrication, and calibration plans of some firmness sensing methods will be shared among all the cooperating stations. More specifically, on impact property evaluation, GA, ME, MI, ARS-MI, and WA stations will be working together; and GA, ME, MI, NC, ARS-MI stations will be working together on firmness evaluation. ME will be using the volatile analysis device developed at ARS-MI for fruit maturity evaluation. These locations with specialized analytical equipment, facilities and/or experienced staff will continue to be available. Fruits and vegetables will be shipped to these facilities for analysis or other station members may perform experiments on site.

**C. Evaluate selected chemical and viscoelastic properties that can be used as an indicator of fruit and vegetable quality.**

Nondestructive apple quality assessment using chlorophyll fluorescence will be conducted. Measurements on chlorophyll fluorescence will be correlated with fruit maturity, flesh firmness, storability, and storage scald. A prototype device will be constructed using chlorophyll fluorescence for measuring quality of individual fruit on a commercial packing line application. Detection of flavor and pathogen volatiles can also be used to assess fruit and vegetable quality nondestructively. For this study, the volatile profile of whole and/or lightly processed vegetables and the volatile profiles of the three most important human pathogens (Listeria, Clostridium, Salmonella) and mold will be evaluated. These volatile profiles will be related to quality parameters including shelf life under retail and consumer storage conditions. Signature volatiles or volatile classes for rapid and efficient sorting of fresh fruits and vegetables will be identified (CA, ME, ARS-MI, NY-C). Rapid detection of flavor and pathogen volatiles to non-destructively assess quality of whole and/or lightly processed carrots, lettuce, broccoli and cabbage is a joint project of ARS-MI, MI and WA. NY-G will evaluate the suitability of using the intrinsic enzyme activity as an indicator of fruit and vegetable quality. For example, correlation between the firmness of apples and the levels of cellulase, xylanase, polygalacturonase, and possibly other enzymes will be established.

Shear-based viscoelastic properties of carefully prepared and selected skin and tissue of fruits (e.g., apple, peach, and pear) and vegetables (e.g., cabbage and tomato) will be determined (NY-G). The goal is to understand the role of different cultivars and, where applicable, storage conditions, as well as the influence of measurement temperature. Both small amplitude oscillatory and creep tests will be conducted in the linear viscoelastic range with a Carri-Med CSL2 controlled-stress rheometer. Parallel plate geometry with roughened
surfaces to prevent slip at sample-plate interface will be used. The Peltier plate of the rheometer will be used to accurately control the temperature of the test samples. Descriptive models will be developed for the properties at a fixed temperature and the influence of temperature on the properties.

D. Develop advanced electromagnetic methods for determining fruit and vegetable quality.

Considerable success has been shown in using X-Ray and nuclear magnetic resonance (NMR) as a nondestructive method for measuring fruit and vegetable quality. X-ray methods for detecting insects in mangoes will be evaluated (HI). In the early stages fruit that have been treated to kill any insects will be sent to Georgia for x-ray imaging. Since the treatments available for killing the insects are unacceptable in high quality markets further tests will be done with equipment available in Hawaii. Work is continuing regarding the X-ray properties of fruits in storage. Changes in tissue absorption properties while in storage which were precipitated by an initial impact bruise are being studied. These studies are using line scanning along with X-Ray CT. Plans are being formulated to investigate X-Ray energy levels less than 120KV (GA, NY-C).

An X-Ray CT scanner is available at GA and an NMR facility is available at CA. As a result of joint work on watercore in apples, changes in tissue absorption properties in apples while in storage will be studied using spectroscopy along with X-Ray CT. Characteristics of new and stored, bruised and unbruised tissue will be examined (GA, NY-C).

Measurement of $^1$H-MR spin-lattice and spin-spin relaxation parameters requires that standardized sucrose solutions be available for calibration. Each station has distinctly different $^1$H-MR equipment and standardization with these sucrose solutions will allow a comparison and evaluation of equipment performance. Sterilized sucrose solutions will be prepared (IN) and sent to the other stations for calibration and testing.

Proton magnetic resonance devices are also available (IN). The application of proton magnetic resonance ($^1$H-MR) will continue with investigations into non-destructive measurement of fruit and vegetable ripeness and quality. Changes in equipment and methods which will increase the precision of soluble solids measurements will be evaluated. Commodities to be evaluated will include apples and oranges. Applications of $^1$H-MR to quality control processing of tomato products, and fruit and vegetable purees will also be studied (IN).

NMR will be used to determine if oil content of macadamia nuts can be determined when the nuts are moving through the magnets of the NMR equipment (HI, CA, IN).
Researchers (CA) will continue to work with other researchers to investigate potential uses of NMR techniques for evaluating internal quality of selected fruits and vegetables. Equipment to singulate and transport macadamia nuts through the magnets of NMR equipment will be developed if oil content can be determined in moving nuts (HI).

$^1$H-MR sensing will be evaluated for detection of the maturity of unshelled peanuts and detection of maturity and quality of unshelled Macadamia nuts (HI, CA, IN).

The use of $^1$H-MR for detection of soluble solids, water core, firmness, and other quality factors in apples will be evaluated. Apples will be provided (NY) with quality defects or variations in firmness. These apples will be shipped for testing in the $^1$H-MR sensing laboratory (IN, NY-C).

**E. Evaluate visible light and NIR as indicators of fruit and vegetable quality.**

Stations with spectrophotometers (CA, ME, NY-C, GA) will provide facilities in which to do spectral analysis of fruits and vegetables on an available basis. It will be important to be able to do reflection, transmission and fluorescence spectroscopy in the ultraviolet, visible, and infrared parts of the spectrum. Cooperative projects will occur between centers of spectroscopy and those stations that have machine vision applications (AR, CA, HI, MI, NJ, NY-C, PA). Electronically controlled filters are available for the visible and near-infrared spectra.

Measurement of reflectance properties of fruit/vegetable samples with the variable electronic filters at the NY station will be critical. Samples may be sent to other locations, equipment may be sent to Michigan and/or respective researchers may travel to either the fruit or equipment location to conduct this cooperative research. It is also expected that cooperation will exist in sharing of results and data interpretation and ultimately in co-authorship of papers.

ARS-WV, ARS-MD and CA will cooperate in the development of NIR sensing techniques. Such cooperation, which may include sharing of sensor design techniques and cooperative system testing on actual commodities, will depend upon the restaffing and program redirections currently being considered at ARS-WV and ARS-MD. Collaborative efforts will be undertaken (CA) to develop NIR sensing techniques for evaluating the quality of fruits and vegetables. These activities will include sharing of sensor design techniques and testing commodities across regions CA, ME).

**F. Consider advanced technologies as possible indicators of fruit and vegetable quality.**
Emerging technologies will allow the use of other types of energies - possibly electrical (EM fields, microwaves, etc.). There are no current plans in these areas but during the duration of the project other developing and appropriate technologies will be investigated. Biosensor technology will be investigated to detect biochemical constituents in low concentration for measurement of food quality and safety. Molecular recognition in the sensor will be achieved by immunoreaction between an antibody and the particular antigenic determinant, and signal transduction will be based on photometric sensing. Problems to be considered will be the on-line sensing of aromatic components from fruits (stone fruits and apples) and detection of molds and mycotoxins in fresh and processed foods (CA).

Objective 2: To develop sensor technology for quantitative measurement of fruit and vegetable properties indicative of quality.

Preface:

Research will be conducted to develop new and evaluate improved sensing techniques which are suitable for high-speed determination of quality. Emphasis will be placed upon identifying and developing sensing technologies that have a level of sensitivity which will allow integration into high-speed handling systems currently used by industry. A number of different technologies will be investigated.

A. Electronic image processing technology.

Electronic image processing systems are available at each of the cooperating stations. Electronic images can be produced by all the appropriate energies. Therefore, common software techniques can be developed and shared for processing two-dimensional sensory images that are independent of the energy detected in generating the image. These generic techniques are useful in the initial investigations that determine the suitability of a sensor or sensory system. Software for pattern recognition, feature extraction, and on-line adaptive learning are techniques that have been shared and will continued to be used within the project. The development of integrated grading or inspection stations is a logical outcome of the development of sensors within this objective. There are sensory systems that have been developed in the previous project that are now being evaluated or used for on-line inspections.

The application of electronically tuned optical filters as spatial reflectance spectroscopes will be evaluated. Tunable filters in both the near infrared and visible spectra are available. Standard reflectance spectroscopy techniques, integrating spheres, and fiber
optic/photodiode array spectrographic systems are available for comparison to tuned filters. These tools will be used to capture surface defects on a wide variety of apple cultivars. Surface defects will be identified by researchers including entomologists and plant pathologists. Image processing techniques will be applied to these data to enhance and distinguish the surface defects (NY-C).

Spectral properties will be studied and verified with electronically controlled variable filters. Machine vision and materials handling will be developed in an effort to proceed to a functional practical system and prototype development (NY-C, MI). Research will continue on identifying bruising and cracking defects on dark sweet cherries. We expect research in this area to expand with similar procedures to other commodities. Initial plans are being considered to study potato defects (MI).

Two dimensional human vision can be simulated with the availability of a true color camera and vision system. Grading of fruit and vegetables are often based on state and federal grade standards, which specify color. Color computer vision will be used for maturity, defect identification, and orientation determination for peaches, apples, potatoes, cherries and blueberries (AR, CA, MI, NY-C, PA, ME).

Cooperating stations (CA, MI, NJ, NY-C, PA) will jointly develop and exchange machine vision algorithms for processing computer images (see critical review). Although, individual projects may address different commodities and/or defects, the basic algorithms for enhancement, filtering, segmentation, representation, as well as analysis techniques will be very similar.

B. Adapt and innovate high-speed produce handling and sensing technologies.

Mechanical energies needed to transport the product also impart damage to fruits and vegetables during handling. Prevention of damage is as important as detection and proper presentation is important for inspection stations. Reduced damage due to handling and singulation of fruits and vegetable using a wave conveyor will be examined. The effect of wave pitch and diameter will be correlated to damage and the singulation produced by the conveyor (ARS-MI).

Integrated grading and inspection stations are being designed and will be evaluated. Inspection systems have been developed for pears with good success. Specialized pipeline processing techniques have been used in the process to produce the necessary processing speed. This inspection system will continue to be evaluated and applied to other fruits (CA).

Sensors developed under static conditions must be adapted for high speed on-line conditions. The system requires the integration of mechanical movement, the sensor and
the device delivering energy to the fruit or vegetable. Detection of surface defects and bruises in on-line systems are being developed for apples and potatoes that use visible and near infrared sensors (AR, NY-C, PA). Fruit presentation to the camera (oriented versus non-oriented with stem/calyx identification), camera placement, and image capture for total surface coverage are all areas of concern for on-line systems (AR, CA, NY-C, PA).

At NY-C an inspection system for automatic sensing of apple defects at a rate of 6 - 10 apples/second is being developed. A commercial conveying line will be evaluated and modified under laboratory conditions. Image processing algorithms will be revised to match the processing requirements of on-line speeds and examination of images for bruises and common defects. The laboratory system will be evaluated with a large number of apples from many different cultivars. Final evaluation will take place in a grading shed of a major apple processor in the Northeast who is identified and has indicated an interest in cooperating. Statistical comparisons between the USDA inspections done at this site and the automatic inspection station will be completed. The final phase will include finding a manufacturer of apple handling equipment to build the automatic inspection system and to incorporate as much of the image processing in hardware as possible to reduce the time to process each apple (AR, NY-C).

NY-C will continue planning and sharing of equipment, ideas, and resources to accomplish the task of building an automatic inspection for apple defects. Without these combined efforts, resources, and ideas, the magnitude of design considerations and development cost for an automatic inspection station would be impossible in a reasonable time frame. PA and other stations will be invited to evaluate the completed air-puff firmness detection system developed at Georgia. Progress made by other stations will be used for the image analysis part of the detector (GA). Results of the contact pressure based firmness sensor being developed at Michigan will be compared with that developed in Georgia and North Carolina.

Work is continuing on the development of high-speed NMR techniques for sensing internal quality of fruits and vegetables while they are moving on a conveying belt (CA). The existing conveying belt will use different spectrometers to develop high-speed NMR techniques for determining soluble solid contents of selected fruits, and detecting internal tissue breakdown and presence of unwanted objects in fruits and vegetables.

The technique of using a puff of air to cause a deformation measured with a laser displacement sensor has been developed into a firmness detector. Work will include research needed for the design and testing of an automated system firmness detector suitable for off-line users such as quality control inspectors, USDA inspectors, warehouse managers, and retail store clerks. A three axis positioning stage will be built to align the fruit with the
center of the air nozzle. Fruit centerline will be determined by making a line scan with the laser displacement sensor or through image analysis from two cameras at 90 degree angles. Geometric configuration improvements to the detector head will be investigated (GA).

Objective 3: To develop methodologies for classification and sensor fusion which facilitate optimal fruit and vegetable quality discrimination.

A. Develop common data sets which can be shared among laboratories equipped to evaluate advanced sensing system approaches.

Laboratories exist among project members which contain highly specialized equipment such as visible light (VL), near infrared (NIR) transmittance or reflectance, magnetic resonance (MR), x-ray evaluation or acoustical evaluation for measuring quality attributes. Other laboratories are well equipped to perform detailed physical property evaluation of fruit and vegetable quality. A chief limitation within some of these laboratories is the lack of equipment and perhaps expertise in performing the accepted standard tests for fruit and vegetable quality determination. Another limitation is the inability, due to lack of knowledge, to properly combine inputs from multiple sensing approaches. Equipment for measuring impact properties and firmness will be shared among cooperating stations. Design, fabrication and calibration plans of some firmness sensing methods will be shared among all the cooperating stations. More specifically, on impact property evaluation, GA, ME, MI, USDA-MI, and WA stations will be working together; and GA, ME, MI, NC, USDA-MI stations will be working together on firmness evaluation. Development of shared data sets will enable appropriate sensor fusion coupled with excellent physical property evaluation and accepted evaluations with respect to various grade standards.

B. To evaluate a suite of techniques such as neural net, fuzzy logic, canonical correlation, principle components analyses, discriminant analyses, regression analyses, pattern recognition approaches and hierarchal classification (e.g. CART) for efficacy in signal processing in selected quality determination applications.

Several of the above techniques are suited to understanding relations between and among multiple outputs from a single sensor type as related to multiple outputs from a detailed physical property evaluation (e.g. fuzzy logic, canonical correlation, principle components). Such approaches will be used to better understand existing x-ray, NMR and mechanical evaluation methods by relating them to detailed physical property evaluation results. Shared data will enable these evaluations.
Techniques noted above exemplify methods which accommodate multiple inputs. Depending on the nature of the input (e.g. continuous or discrete), the correlation which may or may not be present with multiple inputs, and possibly other as yet unidentified factors, the optimal technique will probably change with specific application. Not all laboratories are equally proficient in making each evaluation. Especially with neural nets and other pattern recognition approaches, architecture possibilities are quite diverse and coordinated testing in multiple laboratories would enable a more complete evaluation. Data will be shared among cooperating laboratories enabling each method to be evaluated in a coordinated fashion. Cooperating stations (CA, MI, NJ, NY-C, PA, USDA-WV) will jointly develop and exchange machine vision algorithms for processing computer images. Although, individual projects may address different commodities and/or defects, the basic algorithms for enhancement, filtering, segmentation, representation, as well as analysis techniques will be very similar.

C. To develop criteria and evaluate selected sensor fusions enabling integration of existing sensor technologies into efficacious quality sensing systems.

Approaches and shared data of Objective 2 would be extended to multiple sensing platforms. Initial evaluations would be made combining sample weight with optical properties because both are very common. Visible light-based results may then be fused with x-ray based data in cases where x-ray is currently used (e.g. potato hollow heart evaluation). Mechanical firmness outputs may then be fused with visible light data in selected applications. Practicality and economic feasibility considerations would be considered along with likely benefit when selecting candidate sensing approaches for sensor fusion studies.

Fuzzy logic, discriminant analyses and neural networks provide convenient approaches for fusing or melding results from multiple sensor types and consequently will receive the most attention. From the knowledge base developed in this objective, criteria development for selecting and fusing sensing system approaches would be attempted. Knowledge learned would be integrated into packing line equipment.

EXPECTED OUTCOMES:

The development of integrated grading or inspection stations is an overall outcome of this project. The following are the specific outcomes:

The project will develop a standardized impact properties measurement method for fruits and vegetables. With a standardized method to quantify impact properties, a database of impact susceptibility of different
fruits and vegetables can then be established. This information would be useful in selecting and handling different varieties of fruits and vegetables thereby reducing damage during sorting and handling.

Nondestructive firmness sensor for fresh fruits and vegetables will be developed. Firmness is considered an indicator of the storability and eating quality of fruits and vegetables. This will improve the overall quality of fruits and vegetables on the market and value to the products. Firmness information will help the packinghouse managers in deciding where to market their products.

Sensors to measure parameters such as maturity, color, shape, size, surface and internal defects for the dynamic environment for on-line, accurate, high-speed grading and inspection will be developed. These sensors will have similar benefits as discussed above under firmness. Another outcome of the project will be classification methods based on techniques such as neural network, fuzzy logic, canonical correlations discriminant analysis and or pattern recognition. Optimum sensory system based on sensor fusion would enable more accurate sorting decisions.

New sensor technology may make it possible to sort for quality not currently defined. For example, along with optical weight data, modalities such as NIR and X-ray linescan may be used to detect watercore in apples. It is expected that as a result of this project, the overall quality of fruits and vegetables in the market would increase which would make the U.S. growers more competitive in the domestic and foreign markets. Having higher quality products in the market, the consumption of fruits and vegetables will increase thereby improving nutritional intake.

ORGANIZATION:

The Regional research project organization has been established in accordance with the format suggested in the "Manual for Cooperative Regional Research". One person at each participating agency is designated, with approval of the agency director, as a voting member of the Technical Committee. Other persons at agencies are encouraged to participate as non-voting members of the Technical Committee.

An Executive Committee, consisting of the Chairman, Secretary, Industry Liaison, Member-at-Large, and Administrative Advisor will conduct the activities of the regional project between annual Technical Committee meetings. Additional duties of the Executive Committee are as outlined in the Manual for Cooperative Regional Research. Membership on the Executive Committee is not limited to the official voting representatives. The Executive Committee is elected annually by voting members of the Technical Committee with the exception of the Industry Liaison. The Industry Liaison will be elected for a three year term, and will be responsible for informing industry representatives about yearly committee activities. Normally, a succession of offices from Member-at-Large to Secretary to Chairman is desirable, but is not established pro-forma. All members of the Executive
Committee will be elected each year. No member shall hold the same office in consecutive years.
NE-179
Technology and Principles for Assessing and Retaining Postharvest Quality of Fruits and Vegetables

SIGNATURES:

Chairman, NE-179 Project Outline Revision Committee  Date

Administrative Advisor  Date

Chairman, Regional Association of Directors  Date

Chairman, Committee of Nine  Date

Chairman, Cooperative State Research Service  Date
REFERENCE:


aperture for maximum contrast between bruised and unbruised apple tissue. ASAE Paper 933595.


ATTACHMENTS:

PROJECT LEADERS
REGIONAL PROJECT No. NE-179

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*Technical Committee voting members are designated by PI for each station.*
Michigan  
Srivastava, A.-PI  
Phys Prop/Sensor Fusion  
Guyer, D.  
Automated Inspection/Machine Vision

New York-C  
Aneshansley, D.-PI  
Automated Inspection/Machine Vision  
Throop, J.A.  
Automated Inspection/Machine Vision

New York-G  
Hang, Y.D.-PI  
Food Enzymology  
Rao, A  
Food Engineer

North Carolina  
Rohrbach, R.-PI  
Machine Systems / Auto. Inspection

Pennsylvania  
Heinemann, P.-PI  
Automated Inspection

Indiana  
Stroshine, R.L.-PI  
Physical Properties, Proton Magnetic Resonance Sensing

Washington State  
Hyde, G.-PI  
Process Automation  
Pitts, M.  
Instrumentation  
Davis, D.  
Physical Properties  
Patterson  
Quality Evaluation  
Cavalieri, R.  
Postharvest Systems
RESOURCES:

REGIONAL PROJECT No. NE-179
Technology and Principles for Assessing and Retaining Quality of Fruits and Vegetables
(Oct. 1, 1997 - Sept. 30, 2002)

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CRITICAL REVIEW:
REGIONAL PROJECT No. NE-179
Technology and Principles for Assessing and Retaining Quality of Fruits and Vegetables

Accomplishments of the NE-179 regional research projects are reviewed here. The period covered is from October 1, 1991 through September 30, 1997. The review is presented according to the objectives and the publications are organized according to the participating stations. Need for continuing research is indicated where appropriate.

A workshop organized by the NE-179 regional project members (all member stations were heavily involved) entitled "An integrated nondestructive on-line system for quality evaluation of fruits and vegetables" was conducted in 1993 to present state-of-the art techniques useful for nondestructive quality evaluation of fresh fruits and vegetables, and to identify missing knowledge necessary for commercial implementation of a comprehensive on-line integrated system. The conference proceedings were published which reviewed the status of many sensing technologies for quality (firmness, temperature damage, geometric properties and surface texture, surface color, surface defects, internal disorders, interior voids and foreign inclusions, and internal composition) evaluation. Since the quality of each produce item may be based on the aggregate values for several different quality parameters, each measured by different technologies, a data base on a matrix system was developed to summarize the status of nondestructive quality sensing for each crop. (CA, GA, HI, MI, NJ, NY, NC, PA, IN, WA, ARS-GA, ARS-MD, ARS-MI, ARS-WV)

Objective 1: Define quality and measures of quality from the structural, anatomical and physiological properties of fruits and vegetables and their functional relationships to quality.

QUALITY ATTRIBUTES

Mechanical Properties

Mechanical properties of quasi-statically loaded apple tissue (compressive stress vs. strain, tensile stress vs. strain and shear vs. shear strain with tissue oriented parallel to the core line or perpendicular to the core line) and peaches (laser-puff firmness, puncture force) of five firmness groups (from very firm to very soft) were collected. Initial analyses indicated that the apple tissue had a lower Young’s Modulus in compression than in tension, and that the tissue was weaker in tension than in compression. The apple tissue was stiffer and stronger when loaded parallel to the core line compared to loading perpendicular to the core line. Failure stress was highest parallel to the core and lowest in the tangential direction. Young’s modulus was highest in radial samples. The largest values of failure stress and Young’s modulus were obtained from the calyx end and the smallest Young’s
modulus values, from the shoulder. Delicious apples varied more around their circumference than did Golden Delicious and Rome Beauty apples. The anisotropic properties were most pronounced in equatorial sections.

Theoretical analysis and experimental measurements were conducted to determine the vibration modes in apples. The studies provide detailed information on the vibration modes associated with the first three resonant frequencies of an intact apple. Since the mode shape tells us how the fruit vibrates at different locations with respect to the input impulse, it is important to know the correct vibration mode of each resonance frequency so that one can place the detector at the correct position in order to obtain the desired acoustic measurements. Information obtained from these studies will be useful for the future development of acoustic techniques for quality evaluation of fruits and vegetables (CA, ARS-MD, WA).

Finite Element Modeling

A finite element model with 2000 elements was constructed and evaluated typical Red Delicious apples. The model is capable of modeling large (64 count) to small (125 count) apples ranging in aspect ratios from 0.9 to 1.2. Material properties in regions under the transducer and/or receiver can be adjusted to simulate bruise and/or sunny side effects. The model simulates both quasi-static loadings and resonant vibration (assuming appropriate material properties are used), and is available for use by apple firmness sensor inventors (WA).

Finite element models were developed to describe apples with different shapes and sizes, in which the axisymmetrical geometry of the apple was described by a four-parameter equation and the core, by an exponential equation. Three basic classes of vibration modes were identified: torsional, spheroidal, and nonaxisymmetric, with most modes within the frequency range of interest belonging to the latter class. Shape was shown to influence resonant frequencies of all modes. Inclusion of a shape factor in the firmness index should improve firmness prediction. The properties of the skin had the greatest effect on resonant frequencies of the torsional modes, while core characteristics most affected spherical modes. The differential effects of shape, skin, and core have implications for instrument design (ARS-MD).

A finite element model of a potato as loaded by a spherical indentor was constructed. It was found that the peak von Mises Stress was located below the surface at a distance about half of the indentor diameter. This location coincides with the location of blackspot bruising of potatoes. It was also found that the von Mises stress may exceed the yield stress even if the surface pressure is below the yield point (MI).

Firmness

A nondestructive, non-contact firmness detector based on a laser displacement sensor (described under objective 2) was used to measure the deformation caused by a puff of air.
Correlations with Magness-Taylor tests on tomatoes, peaches, and apples were in the range of $r^2 = 0.75$ to 0.87. The elastic modulus determined from the air-puff correlated well ($r^2 = 0.89$ and 0.91) with those measured by spherical indenter tests. (GA)

Sorting accuracy for the laser-puff detector was 79%, 76%, 80%, 68%, 82% for very firm, firm, neither firm nor soft, soft, and very soft, respectively; with none of the peaches assigned to a firmness group more than one class different from the expert ranking. This demonstrated that the laser-puff detector based on deformation can successfully sort fresh peaches based on firmness.

Maturity

Hawaii attempted to find a relationship between harvest energy for individual coffee cherries and the maturity of the coffee. Neither tension removal force nor impact force gave the degree of selectivity desired. Structural differences due to maturity could not be detected by differences in the two methods of removal since there appeared to be no difference. Production, harvesting and/or site conditions have been suggested as possible sources of the problem of softening of tart cherries. The problem is of significant importance because it creates subsequent handling and pitting problems. Studies involved measuring orchard site conditions, production practices and environmental conditions and relating these to changes in fruit physiology and chemistry have been conducted.

One of the primary measurements made on the fruit before and after harvest and handling is firmness measurement using a force deformation device. With better understanding of the changes taking place in cherry as related to softening, what properties of the cherry the firmness device is measuring can be explained. (GA, HI, MI, WA, ARS-MI)

Internal Quality

The potential for using X-rays for inspecting internal quality has been evaluated. Apples, illumination systems, and software algorithms were provided by NY station for the X-ray detection of watercore in apples. An X-ray image was determined to be largely a map of water content distribution within apples. This cooperation allowed for direct comparison of X-ray imaging techniques and light transmission. Insect damage, fresh bruises, corky tissue and void spaces are detectable based on X-ray absorption patterns associated with these features. We believe this same result will extend to other fleshy fruits as well. Preliminary results suggest that pits in stone fruits such as peaches can be detected as well. Image analysis techniques enabling extraction of features associated with corky tissue, fresh bruises, insect damage and void spaces from the image background are currently being researched. (GA, NY, ARS-WV)

Chemical Indicators

Physical and biochemical changes in fruits during storage have been reported. For example,
softening of tomato is caused by pectin solubilization, depolymerization of xyloglucans and over-all changes in the quantity of cell wall polysaccharide fractions. There is a high correlation between increase in polygalacturonase and cellulase activities and loss of fruit firmness during mango ripening. The main cause of banana softening is the coordinated degradation of starch, hemicellulose, and pectic substances. Increased activities of pectin methylesterase, cellulase, and polygalacturonase with delay in harvesting time contribute to the quality deterioration of Kinnow mandarin fruits. Loss of flesh firmness during muskmelon ripening is related to enzymatic modifications of pectic and hemicellulosic materials and a significant loss of non-cellulosic neutral sugars. Polygalacturonase and cellulase levels increase for up to 150 days of storage, leading to loss of firmness of Red Delicious apples. (NY)

BRUISE SUSCEPTIBILITY

A new standard for impacting procedures, including constant-height multiple-impacting to determine bruise resistance and tissue impact failure property of most commodities was developed. This comprehensive impact sensitivity evaluation procedure measures statistical bruise threshold, bruise resistance, tissue failure properties, and relative turgor. Bruise damage susceptibility of apple, potato, peach, onion, and blueberries were measured. Drop tests were conducted using the Instrumented Sphere (IS) and four varieties of apples to determine the impact conditions which initiate bruising. 'McIntosh' apples were found to be the most sensitive of the apple varieties. Spartan Banner onions were evaluated to estimate the impact conditions which initiate bruising. Bruising initiated at a lower drop height for the cured onions compared to the freshly harvested one. Bruise threshold response lines were developed and combined with IS impact response lines for typical surfaces used on apple and onion packing lines. Two varieties of blueberries and peaches were dropped onto various surfaces to determine impact conditions that initiate bruising and to identify the amount of cushioning required to avoid or minimize impact bruising. To reduce impact damage and severe bruising during mechanical harvesting all surfaces in the collection systems must be properly cushioned. The information can be used to develop handling equipment design and operation guidelines.

For potatoes, dynamic threshold contact pressures that result in bruising during impact were found. A contact pressure of 1027 kPa resulted in bruising of 'Superior' potatoes while only 880 kPa pressure would bruise 'Snowden' potatoes, making it more susceptible to bruising. The threshold dynamic contact pressure correlated well with mechanical properties such as the yield stress and elastic modulus. PPO (poly-phenol oxidase) activity increased as potatoes bruised. Thus, increased PPO activity can be used to characterize bruise susceptibility. In tubers, increasing strain rate decreased failure strain but failure stress was unaffected; while in apples, increasing strain rate increased failure stress but left failure strain unaffected. Pear tissue failure properties were somewhat like those of tuber tissue. A very important finding was that shock wave speed through tissue samples
provides a new and reliable measure of relative turgor. (GA, MI, WA, ARS-MI)

Objective 2: Develop Sensor Technology for Qualitative Measurement of Fruit and Vegetable Properties Indicative of Quality.

Six technological areas were identified for stations to investigate for sensors that quantitatively measure properties indicative of quality. The areas identified were image processing, measurements using light (visible and near infrared), x-ray, mechanical, acoustic, and electro-magnetic (NMR) energies. Significant progress was made in all areas and some emerging technologies were examined as well.

**IMAGE PROCESSING**

Many stations adapted and/or developed software to analyze visible and near infrared images and other multidimensional sensing data from fruits and vegetables. Sharing of software resources has been significant between stations. There have been two paths in this software development. Software has been developed to enhance the sensor information in an effort to detect defects. This requires understanding and quantification of good or quality attributes as well as defective attributes. Fourier analysis, texture analysis and computed tomography have been two areas of intense interest in this area. The second area is the development of classifiers which generally integrate more than one sensory input or analysis outcome. Statistical classifiers and artificial intelligence systems have been attempted.

Fourier Analysis

A Fourier-based shape separation method was developed for shape grading of potatoes using machine vision for automated inspection. The relationship between object shape and its boundary spectrum values in Fourier domain was explored for shape extraction. A new and fast method of using Green's theorem and boundary Fourier coefficients was given for estimating elongation of an object. A shape separator based on harmonics of the transform was defined for potato shape separation. Tests showed the shape separator was effective and efficient for difficult shape separation. The machine vision system developed has a great potential to assist humans for automated potato grading. (PA)

Texture Analysis

Machine vision techniques for grading raisins and for real-time grading of stone fruits are based on surface texture. The grading system is capable of detecting color, dark spots and concavities. (CA) Texture features of variance and sum variance were found to be useful to detect bruising in apples but required too much processing time for on-line processing (6 - 10 apples/second). (NY, ARS-WV)
Computed Tomography

Changes in tissue absorption properties while in storage which were precipitated by an initial impact bruise are being studied. These studies are using line-scanning along with x-ray Computed Tomography. (GA) X-ray CT was used to separate tomatoes which would respond to ethylene from those which would not do so. An internal transition occurs while tomatoes are in the mature green phase which correlates to favorable response to ethylene treatment. No changes occur externally while this internal change occurs, making an internal detection method desirable. (GA and FL)

A machine vision system for quantifying light transmission was used for detecting watercore disorder in Red Delicious' apples. A Toshiba 20Ax tomographic scanner operated in the line scan mode and an incandescent light box were used to nondestructively detect infected onions. The number and size of defects and the different image intensity were contributing parameters to a discriminant analysis model predicting 70% accuracy. (GA)

Statistical Classifiers

Infected onions were detected using an incandescent light box (NY) and a tomographic scanner (GA). The number and size of defects were predicted with 70% accuracy using a discriminant analysis model. (GA) Nine quality parameters of Golden Delicious' apples were measured during four weeks of storage at four temperatures. Apple color was determined by a Gardner colorimeter and a sensory panel using a 150 mm unstructured horizontal line scale. Hue angle was calculated for the sensory score sheets and measured L, a, b values. Hue angles for the two methods correlated significantly (r = 0.87). (GA)

Algorithms were developed to form a basis for single-pass quality feature inspection and grading of Golden Delicious' apples. The inspection criteria were based on USDA standards for fresh market apples. Image analysis algorithms were developed to assess and quantify the quality features of color, shape, and russet. Over 300 Golden Delicious' apples were inspected by the machine vision system and the results were compared to a human inspector. The vision system was able to correctly classify 100% of the apples for color, 92.3% for shape, and 82.5% for russetting. (PA)

The quality features of the common white Agaricus bisporus mushroom were quantified using image analysis in order to inspect and grade the mushrooms by an automated system. The features considered were color, shape, stem cut, and cap veil opening. Two human inspectors evaluated samples which were divided into training and test sets. The vision system was trained to classify mushrooms into two quality grades using thresholding. The human inspection results were compared with each other as well as the computer vision system results. Misclassification by the vision system ranged from 8 to 56% depending upon the quality feature evaluated, but averaged about 20%. The disagreement between inspectors ranged from 14 to 36%. (PA)
Artificial Intelligence

Relative strengths and weaknesses of artificial neural networks versus traditional statistical classifiers were addressed. Performance of the backpropagation neural network and the Fisher discriminant function were compared for machine vision inspection of greening, shape, and shatter bruise in potatoes. The training sets consisted of 34 potato samples for greening, 20 potato samples for shape, and 28 potato samples for shatter bruise detection. The test sets consisted of 20 potato samples for greening, 14 potato samples for shape, and 30 potato samples for shatter bruise detection. The backpropagation network and the Fisher method both performed with a 70% accuracy for greening. The backpropagation method performed better for shape discrimination with a 78.6% accuracy versus a 71.4% accuracy. The Fisher method performed better for shatter bruise detection with a 76.7% accuracy versus a 50.0% accuracy for backpropagation. (PA)

VISIBLE AND INFRARED LIGHT ENERGIES

Much of the inspection and grading of fruits and vegetables is done by human with advantages and disadvantages. Research in this area has addressed the disadvantages of the human by examining spectral characteristics within and beyond those of humans (NIR particularly). Spectral characteristics of quality parameters have been used to improve detection of defects (difference between good and poor quality) either in with assistive devices (color blocks for comparison, improved lighting) or by automating the process (electronic imaging systems). However, there is also use of this technology in perform inspection tasks that the human can not accomplish (detection of internal defects, constituent analysis, etc). Both of these areas have been addressed by the stations under this objective.

Assistive Technologies (Color Standards and Lighting)

Dark sweet cherry skin color is an important criterion used to judge harvest maturity. Colorimeter measurements were made of the skin color of three dark sweet varieties. A set of eight color chips were developed in 1993 based on the color data collected. The color chips closely match the actual color changes of the cherries. (ARS-MI, MI)

Spectral reflectance measurements of several fruits and vegetables, and typical surface defects that must be visually recognized by human sorters, were combined with the sensitivity of the human eye to show which light sources may help workers with their sorting task on commercial packing lines. Guidelines were developed that should improve the accuracy of sorting, reduce worker eyestrain and fatigue, and provide good alternatives for replacement lighting systems. (ARS-MI)

Lighting for manual grading of onions and potatoes in Washington was found to be generally below recommended intensity and color rendering index for these commodities, with too much use of white sorting surfaces. (WA)
Nine quality parameters of 'Golden Delicious' apples were measured during four weeks of storage at four temperatures. Apple color was determined by a Gardner colorimeter and by a sensory panel using a 150 mm unstructured horizontal line scale. Hue angle was calculated from the sensory scores and the measured L, a, b values. Hue angles from the two methods correlated significantly (r = 0.87). (GA)

A low cost destructive compression testing system to be used by blueberry researchers to compare firmness results was developed. A BARD project (NC-Israel) was also initiated to fund additional work with the NCSU fruit impact contact-pressure sensor in the US, and acoustic analysis of firmness in Israel on tomatoes and apples.

Automated Technologies (Imaging Systems)

Machine vision systems were developed to measure color according to industry color standards and to detect defects. The defect detection part concentrated on using structured illumination to detect surface concavities and, thus, not confuse them with actual defects. Image processing was done in real-time (up to 14 fruit/s) with a stream-lined algorithm implemented on a pipe-line system. (CA)

Techniques and technology are being tested to determine if potential exists to electronically detect bruising and skin cracks on dark sweet cherries. Spectral characteristics of each defect have been determined using a spectral radiometer. This information is being used as the basis for machine vision system. A combination of visible and non-visible wavelengths have shown potential in discriminating these defects from good quality tissue. The project is currently considering techniques and materials handling to develop a prototype system. The problem being addressed is of importance and interest to all sweet cherry growing regions (MI, ARS-WV).

A sorting line for shape defects of sweet potatoes developed and tested using B/W TV as the primary sensing technique. (NC)

Bruise detection using images of NIR and visual reflectance from the apple surface was investigated to optimize lighting, lens aperture, and camera sensitivity for greatest contrast between bruised and unbruised tissue, improve algorithm efficiency, increase the number of discriminate features (co-occurrence texture features), and improve the present processing algorithm to detect both fresh (24 hour) and stored bruises (≥ 2 months) from unbruised tissue. Combining NIR and green reflectance features from images of 'Golden Delicious' apples showed promise as a way to improve bruise detection over just using NIR reflectance which has historically worked poorly on green/yellow cultivars. A study of bruising on stored apples showed the change in reflectance from less than to greater than unbruised tissue while in storage. An algorithm for locating bruises in NIR apple images was improved to detect both 24-hour and 2-month old bruising. The time to process apple images with this algorithm was reduced from 5 seconds per apple to 1 second per apple through improvements in computer hardware. (NY, ARS-WV)

Spectral reflectance curves and filtered images of common defects including fly speck, sooty blotch, codling moth, insect stings, punctures, bruising, hail damage, scab, russet, leaf
roller, sun scald, and bitter pit have been collected. This information will be analyzed by the end of 1996 to determine if the wavelength of the reflected light can be used to identify these defects from undamaged tissue and each other. (NY, ARS-WV)

Image analysis algorithms were developed to distinguish between good and greened potatoes and yellow and green 'Golden Delicious' apples. The method of using the HSI (Hue, Saturation, and Intensity) color system proved highly effective for color evaluation and image processing. The vision system achieved over 90% accuracy in inspection of potatoes and apples by representing features with hue histograms and applying multi-variate discriminant techniques. Reducing the number of hue bins by selecting significant features only or by summing groups of hue bins increased misclassification by the vision system. Color classification represents an important quality feature evaluation method that needs to be integrated into an overall automated quality inspection and grading system. (PA)

Internal and Constituent Analysis

An optical technique has been developed that uses NIR absorption characteristics for predicting soluble solids content, sucrose content, and chlorophyll content in peaches and nectarines. (CA) Color changes of mango were found to be unrelated to soluble solids and titratable acid. (HI)

Internal watercore damage was detected by transmitting visible and near infrared (NIR) light through each fruit and capturing images with a sensitive digital camera. Non-watercore damaged apples could be separated from 99% of the damaged apples regardless of the level of damage. Slightly damaged fruit could be separated from moderate to severely damaged fruit 95% of the time. It was discovered that this technique must be applied within the first 6 - 8 weeks of storage because internal changes occur within the apple causing watercore to be undetectable. (NY, ARS-WV, also see X-RAY, GA)

Internal browning in apples could be classified from the intensity of transmitted light at 720 nm and 810 nm. Less than 10% of the fruit with internal browning and less than 7% of the undamaged apples were misclassified. The low light levels transmitted makes this nondestructive technique hard to apply on-line. (NY, ARS-WV)

UV stimulation of apples has been explored to determine the NAD+/NADH and NADP+/NADPH fluorescence ratios and to see if they were an indicator of respiratory activity (maturity). The work showed some promise in 'Golden Delicious', but failed in 'Red Delicious' strains due to the presence of anthocyanins. Further work is needed. (WA)

The NIR absorbance spectrum of freshly harvested unripe kiwifruit were measured. The fruit were then ripened under controlled conditions and the soluble solids content determined. Results show that the nondestructive NIR measurement on the unripe fruit can be used to predict the soluble solids content in ripened fruit (r=0.96) as determined by a refractometer within +/- 1.5 % Brix (CA).

X-RAYS
Internal quality is difficult, although not impossible, to assess using transmitted light. Low light transmitted levels make it particularly difficult to use in automated, on-line systems. X-rays are obviously an energy used to examine internal characteristics. Computed tomography x-ray images were obtained for Red Delicious apples under varying moisture and density states. The results indicated that detectable differences in the images were associated with variations in volumetric water content (GA).

A comparison of x-ray CT (120KV energy level) and the light transmission technique (see Internal and Constituent Analysis under Sensor using visible and NIR light, NY, WV) showed that both techniques reliably separated mild, moderate and severe watercore apples with high accuracy when the test was done immediately after harvest. As storage time increased, changes occurred within the fruits which led to the disappearance of watercore in most mildly and some moderately affected fruits. Most severely affected fruits had to be removed from the test based on appearance. Preliminary evidence shows that watercore can be detected with x-ray line scanning, which has potential for on-line application. (GA)

Several other questions are currently being explored. Work is continuing regarding the x-ray properties of fruits in storage. Changes in tissue absorption properties while in storage which were precipitated by an initial impact bruise are being studied. These studies are using line scanning along with x-ray CT. Plans are being formulated to investigate x-ray energy levels less than 120KV. (GA)

X-ray CT was used to separate tomatoes which would respond to ethylene from those which would not do so. An internal transition occurs while tomatoes are in the mature green phase which correlates to favorable response to ethylene treatment. No changes occur externally while this internal change occurs, making an internal detection method desirable. This work was done by UGA and U Florida. (GA)

Split pit detection in peaches was not investigated because funds were not available. Some work, done at Clemson shows promise. (GA)

NUCLEAR MAGNETIC RESONANCE

NMR techniques were developed for determining oil content in avocados, sugar contents in fresh prunes, presence of pits in cherries, and tissue breakdown in melons (CA). Macadamia nuts were tested using NMR equipment (IN, CA). Correlations of T1, T2, and echo spin ratios to oil content have been promising but without statistically significant results. This cooperative effort needs to be continued. (HI)

The Georgia Experiment station has been working on development of a portable device for detection of peanut maturity since 1992. Proton magnetic resonance (1^H-MR) tests with individual peanuts indicated that maturity determined by scraping and examination of hull color was well correlated with a 1^H-MR index. The index was computed from Free Induction Decay (FID) parameters combined with the magnitude of the spin echo peak at 1 millisecond. In the Fall of 1995, samples evaluated at the University of Georgia were also sent to Purdue University for evaluation with the LF-1A system.
described above. Maturity by hull color was correlated to the spin-spin (T2) relaxation constant combined with the intercept of the semi-log plot of the T2 decay curve. (GA, IN)

MECHANICAL STIMULATION

The actual and perceived quality of fruits and vegetables is dependent on mechanical characteristics. Firmness is an important characteristic, particularly in apples and other fruits. One of the difficulties has been in developing non-destructive technologies that duplicated the standard destructive test (Magness-Taylor) used for firmness.

Quasi-static Loading

A portable data-acquisition instrument was designed and built to rapidly and automatically measure firmness of cherries and berries. The firmness is measured by slightly compressing the fruit between two parallel surfaces and recording the force versus deformation data. The system is capable of distinguishing between bruise treatments, harvest treatments and fruit maturity levels. (ARS-MI)

The portable PC-controlled firmness tester for berries, cherries, and similar small produce was redesigned for continuous automatic operation using a carousel or lazy-susan design. It will measure 25-fruit groups, one fruit at a time, and summarize the firmness statistics. Individual fruits are set in place and removed by hand, but the operation can be continuous at the rate of 25 fruit per minute. The device was demonstrated and accepted by Oregon and Washington sweet cherry growers and packers as a suitable tool for monitoring firmness. A commercial version of the firmness testing system will be available in 1996. (ARS-MI)

A low cost destructive compression testing system was devised to be used by blueberry researchers to compare firmness results. A BARD project (NC-Israel) was also initiated to fund additional work with the NCSU fruit impact contact-pressure sensor in the U.S., and acoustic analysis of firmness in Israel on tomatoes and apples. (NC)

A contact pressure based apple firmness sensor is being developed. The sensor utilizes a commercially available (0.003 in thick) force sensor with a sensing area of 0.25 in. A semi-spherical probe made of soft rubber was used to apply pressure to the apple. The point of minute cell failure as indicated by a drop in the force reading was correlated with the Magness-Taylor reading. A correlation of 0.77 was found. The test caused an acceptable amount of damage to the apple. Further study is needed to test this concept. (MI)

Dynamic/Impact Loading

A free fall impact device for sensing fruit firmness has been developed and tested for pears. The machine was capable of handling about 5 fruit per second. The system could separate fruit into hard and soft classes, but could not resolve 1 lb firmness differences requested by industry. (CA) The free fall impact device (CA) was used to separate different
maturity levels of papaya. A prototype sorter was developed under objective 3. (H1)
Viscoelastic properties of mango were unrelated to titrable acid and soluble solids ratios.
A nondestructive, non-contact firmness detector was developed based on a laser
displacement sensor that measures the deformation caused by a puff of air. A company has
been issued a license for the patent that was obtained. Correlations with Magness-Taylor
tests on tomatoes, peaches, and apples were in the range of \( r^2 = 0.75 \) to 0.87. Even better
correlations \( (r^2 = 0.89 \) and 0.91) resulted with apples and peaches when comparing elastic
modulus calculated from the air-puff with values found from spherical indenter tests. (GA)

Objective 3. Integrate sensor technologies and handling mechanisms
to create a complete evaluation system for fruits and vegetables.

EVALUATING INDUSTRY NEED

A survey is being conducted of the apple industry (packers and processors) to evaluate
their current satisfaction with automated sorting and their future needs and tolerance
expectations for automated sorting. The objective is to help the apple industry understand
the state of current technology and to bring in line the development of automated sorting
systems with the needs of the apple industry. Commercial sorting equipment manufacturers
will also be surveyed in some form to provide feedback on the state-of-the-art of their
equipment. The survey of the packers and processors is in progress and is a cooperative
effort of all stations in the NE-179 project which have apple interests (Coordinated by MI).

Research was conducted on methods for documenting handling systems and
evaluating changes needed, including sensor and sorting technology. The systems approach
developed was published in a reference book which included examples for several crops.
Another tool called "Soft Systems Methodologies" was adapted for evaluating managerial
implications of technological changes. Applications of the methodology have been made
for a wide range of crops and in several countries (GA).

The instrumented sphere (IS) was used to record and analyze impact damage in all
aspects of the postharvest handling of apples. The device was very useful for identifying
areas in the postharvest handling operations that cause impact damage. Avocado, papaya,
pineapple, and onion packing lines were analyzed with the IS and recommendations were
made based upon the impact activity recorded. Approximately 200 commercial IS units
have been sold to countries in Europe, Asia, Africa, South America, North America, and
Australia (MI, ARS-MI).

Through extensive Instrumented Sphere (I.S.) work with potato, apple, and onion
handling equipment, researchers found general problem areas, such as hard supports under
conveyor belts at transfer points and other typical problem areas. Bruise threshold data
were developed for Russet Burbank potatoes and Walla Walla sweet onions for evaluation
of I.S. results. Measurement of these thresholds lead to the impact failure property research discussed under Objective #1 above (WA).

A result of the development of the Instrumented Sphere by ARS-MI and subsequent testing and evaluation of packing lines has resulted in the development of an Extension bulletin related to reducing the problem of physical damage on packing lines. It is designed for packing house managers and installers with suggestions on transfer design between components and cushioning suggestions. Production of the bulletin (E-2290) was a joint effort between MI and ARS-MI stations.

Tests were conducted to identify the magnitude of damage incurred by apples during transportation on trucks and semi-trailers. Damage levels on fruit varied among bin design, suspension type, and trip distance. A trip simulation on a computerized vibration table was conducted for a steel-spring suspension system using different designs of bulk bins. The percentage of apples having abrasion damage was comparable to levels from actual highway tests. Overall the US apple industry can maintain higher apple quality if bulk apples are transported in plastic bins and on semi-trailers having air-cushion suspension (MI and ARS-MI).

A low damage automatic bagger was designed to reduce the kinetic energy in the apples during bagging at the packing house. Bruise/fruit and bruise area/fruit were reduced 93% for Golden Delicious apples compared to the average commercial bagger. This design, if adopted by equipment manufacturers and implemented in packing lines, would maintain high apple quality (MI and ARS-MI).

PROTOTYPE SORTING EQUIPMENT

Poor lighting conditions noted at manual sorting areas on packing and processing lines led to a study by several NE-179 station cooperators. Lighting conditions on sorting lines were evaluated for several commodities in several regions. The result was generally the same in all locations with the light levels being inadequate to optimally identify defects on produce. Various types and intensities of lighting have been studied for several commodities and defect identification. The result has been the recommendation of a special phosphor (SP-30) bulb with specific light levels and belting colors for most commodities. The basic fundamentals of lighting and the performance results of several lighting types along with recommendations on sorting area design have been published in an Extension bulletin (E-2559). This bulletin is in its second printing and being distributed worldwide with very positive feedback. The development of the bulletin was a cooperative effort between MI and ARS-MI stations with initial research cooperation and packing line evaluation from most all NE-179 stations.

The kinematic properties of fruits and vegetables determine how they move through an inspection station. A variety of commercial systems have been tested and have severe limitations in their ability to present products to an inspection station. Apples are a particular example where it will be important to have the apple rotation on the stem/calyx
axis so that the entire surface of the apple can be inspected. Present bi-cone conveying devices orient only apples shaped similar to Red Delicious' apples. Apples varieties grown in the Northeast, other than Red Delicious', will not orient on bi-cone conveyors. Testing of an experimental conveying device is completed that can orient varieties which do not have the elongated pear shape of Red Delicious' apples. This conveying device will be incorporated in a prototype grading system for varieties other than Red Delicious' (NY & ARS-WV).

A prototype machine was developed for sorting husked macadamia nuts from partially husked and unhusked nuts. This machine was capable of processing 30 nuts per minute per channel (HI).

OTHER SORTING TECHNOLOGIES

Equipment based on impact response was built for sorting papaya. This sorter achieved commercially acceptable quality discrimination at speeds approaching 2 fruit per second per channel. Integrating the impact response with other properties such as color and weight will be necessary for commercialization of the papaya sorter (HI). Plans included the development of an impact sorting machine for mangoes until it was determined that apparent modulus of elasticity was not related to the taste attributes or soluble solids and acid ratio. Therefore, a sorting system for mangoes was built. (See objective 2 for a more extensive discussion) (HI).

Over 100 disorders in fruits and vegetables are manifest as a change in specific gravity. A two-phase fluid sorting system was developed and tested for separation of commodities with varying specific gravities. The system was able to separate apples with sp. gr. <= 0.90 from those with greater sp. gr. with better than 90% accuracy regardless of apple size. WSU has applied for a patent on this technology (WA).

A prototype on-line firmness tester using the acoustic response of the apples as a firmness measurement was built and tested to examine the practical considerations for implementing the design into a commercial packing line operation. The tester had the capability to process all necessary information at the rate of 5 apples/s (MI and ARS-MI).

Signal Detection Theory was adapted for use as a tool for evaluating existing sorting equipment or for comparing new equipment or procedures with existing approaches. A sample from the packing line and one from the reject line provides proportion of defects being missed and the good items being discarded. The proportions are then used to calculate the ability of the sorting people or equipment to correctly detect unacceptable items and the bias towards determining an item is defective when it is actually good. The values obtained for detectability and bias enable packinghouse managers to track performance and to compare with typical levels and potential levels (GA).

Results of a recent study, based on both theoretical analysis and experimental evaluation, indicate that a low-mass impactor has many desirable features for a high-speed on-line sensor (CA). An experimental low-mass impact sensor was designed, fabricated,
and tested on a commercial sorting conveyor. The sensor consists of a low-mass (approximately 10 g) swinging impactor that pivots about a low-friction pivot. Preliminary tests indicated that such a sensor could detect fruit firmness at a speed of five fruits per second (maximum speed of the existing conveyor in our lab). The sensor is simple and compact in size. The entire unit (sensor, actuators, and frame) occupies a space of about 4"x 6"x 8". The sensor provides a strong signal and high signal-to-noise ratio. Moreover, the fruit needs not be held fixed during sensing, and the firmness measurement is not sensitive to fruit size (CA).

Researchers in California have demonstrated the feasibility of using an NMR technique for high-speed on-line sensing of fruit quality. Using a specially designed conveyor belt, they successfully acquired FID spectra of avocados while they were moving at speeds up to 250 mm/s. The oil/water resonance peak ratio, obtained from the spectrum, correlates very well ($r^2 = 0.98$) with the dry weight of the fruit. Due to the speed limitation of the conveyor belt driving system, we did not try to use speeds above 250 mm/s. The result, however, clearly shows the potential for acquiring the FID spectra of a fruit at a much higher speed than 250 mm/s (CA).
LIST OF PUBLICATIONS
REGIONAL PROJECT: NE-179
Technology and Principles of Assessing and Retaining Quality for Fruits and Vegetables

REFERRED:

Full Length (Multiple Stations) Sub-total: 13


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Abstracts (Multiple Stations) None

Abstracts None

NON-REFERRED:

Proceedings (Including Meeting Papers) Sub-total, Not Listed: 118
Bulletins Sub-total, Not Listed: 2
Ph.D. Dissertations Sub-total, Not Listed: 3
M.S. Theses Sub-total, Not Listed: 2
Popular Press None
Other (Including Patents) Sub-total, Not Listed: 18