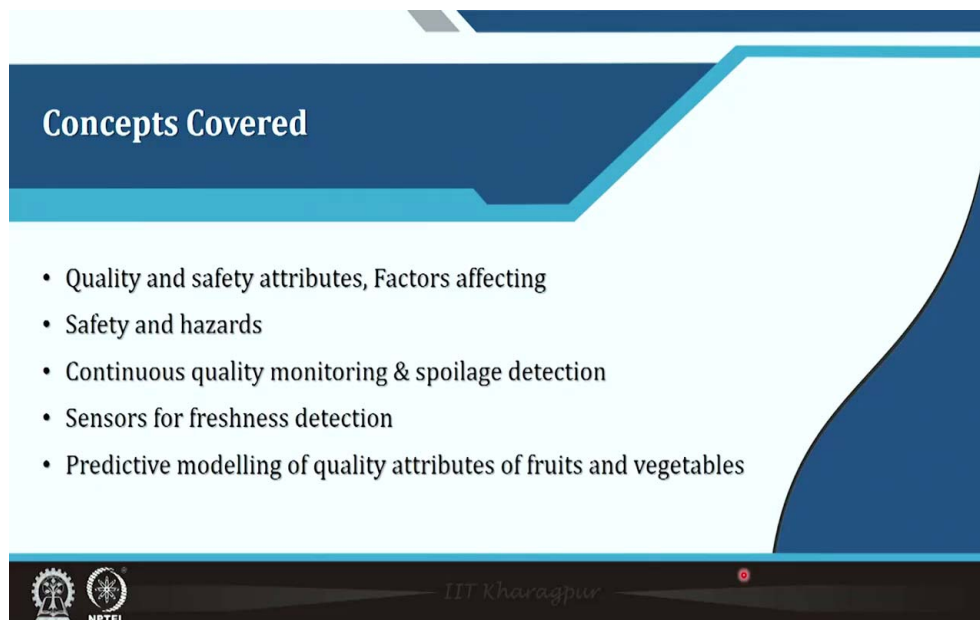


**Post-Harvest Operations and Processing of Fruits, Vegetable, Spices and Plantation
Crop Products**
Professor H N Mishra
Agricultural and Food Engineering Department
Indian Institute of Technology, Kharagpur

Lecture 10
Quality Assurance and Control (QA/QC)



In this lecture the various aspects of quality assurance and quality control protocols will be discussed.



The concept covered of this lecture includes quality and safety attributes of fruits, vegetable and other related commodities, various factors which influence the quality and safety, safety and hazards and after that continuous quality monitoring and spoilage detection as well as

various sensors which are used for the detection of freshness in fruits and vegetables and the discussion about predictive modeling of quality attributes of fresh fruits and vegetables.

Quality

- It refers to the rated ability of a product, whether it is processed product or fresh produce, to perform its functions.
- Degree of excellence of a product or its suitability for a particular use.

Quality assurance

- It is a system for evaluating performance, service, of the quality of a product standard or specified requirement for customers.
- Systematic approach to provide adequate confidence of product and service.

Evaluation of food quality

Subjective (Sensory)	Objective (Instrumental)
<ul style="list-style-type: none"> • Taste • Aroma • Size • Flavour 	<ul style="list-style-type: none"> • pH • Water holding capacity • Vitamin and mineral content

Quality System, Quality Assurance, and Quality Control Relationships

11-04-2022

Source: Donabedian, A. (1996)

3

Quality and quality assurance

The quality of a material refers to the rated ability of a product, whether it is processed product or fresh produce; to perform its functions, proper functions. Quality assurance is a system for evaluating the performance service of the quality of the product standard or a specified requirement for customers.

It is a systematic approach to provide adequate confidence of product and service. Quality system includes quality assurance and quality control and their relationship. However, quality system is a bigger umbrella, which includes quality assurance and quality control. For the evaluation of the quality of a particular fruit, vegetable or any other food there are two types of methods one is the objective assessment other is the subjective assessment.

Subjective assessment generally includes the sensory evaluation or sensory attributes like taste, aroma, size and flavor. In the objective method, generally instrumental approaches are used and various instruments are used for measuring the quality attributes like pH, water holding capacity, vitamin and mineral content etc.

Quality

- It refers to the rated ability of a product, whether it is processed product or fresh produce, to perform its functions.
- Degree of excellence of a product or its suitability for a particular use.

Quality assurance

- It is a system for evaluating performance, service, of the quality of a product standard or specified requirement for customers.
- Systematic approach to provide adequate confidence of product and service.

Evaluation of food quality

Quality System, Quality Assurance, and Quality Control Relationships

Subjective (Sensory)

- Taste
- Aroma
- Size
- Flavour

Objective Methods

- Chemical
- Physiochemical
- Microscopic
- Physical

Source: Donabedian, A (1996).

11-04-2022 3

These objective methods may be further categorized into chemical method, physiochemical method, microscopic method or physical methods.

Undesirable changes in quality attributes

Attributes	Undesirable Changes
<p>Texture</p>	<ul style="list-style-type: none"> • Loss of solubility • Loss of water holding capacity • Toughening • Softening
<p>Flavour</p>	<ul style="list-style-type: none"> • Development of Rancidity (hydrolytic or oxidative) • Cooked or caramel flavours • Other off flavours
<p>Colour</p>	<ul style="list-style-type: none"> • Darkening • Bleaching • Development of other off colors
<p>Nutritive value</p>	<ul style="list-style-type: none"> • Loss or / degradation of Micronutrients (Vitamins, minerals) • Macronutrients (Protein, lipid)

11-04-2022 Prof. H N Mishra, IIT Kharagpur 4

Undesirable changes in the quality attribute

There are various undesirable changes in the quality attributes like in the texture, there may be loss of solubility, loss of water holding capacity, the material may become soft or it may become tough depending upon the various reactions and process which are undergoing in these commodities.

Similarly, regarding flavor there may be development of rancid flavor either hydrolytic rancidity or oxidative rancidity depending upon the nature of the material that may be cooked or caramel flavors, other off flavor development. Like for colour, the commodity may become dark or it may become bleached or a new color may come or there may be development of off colors.

Similarly, nutritive value of the commodity may also get changed and it because of either loss or degradation of micronutrients like vitamins, minerals and macronutrients like proteins and lipids.

Food safety

Assurance that food will not cause harm to the consumer when it is prepared and/or consumed according to its intended use.

- **Toxicity**
Capacity of a substance to produce harm or injury of any kind under any conditions.
- **Hazard**
Relative probability that harm or injury will result when substance is not used in a prescribed manner and quantity.

Physical	any physical material not normally found in food
Chemical	chemicals intentionally or unintentionally added
Biological	living organisms and include microbiological organisms

The slide features a blue and white background with a dark blue curved shape on the right side. A small inset image of a man in a red shirt is visible in the bottom right corner of the slide area.

Food safety

Food safety is the assurance that food after we eat, it will not cause any harm to the consumer. The food will not cause any harm to the consumer when it is prepared or consumed according to its intended use.

Toxicity is capacity of a substance to produce harm or injury of any kind under any conditions. Hazard is the relative probability that harm or injury will result when substances are not used in a prescribed manner or in a prescribed quantity. The hazards may be physical, chemical or biological hazards.

Physical hazards: Any physical material which is not normally found in food.

Chemical hazards: Chemicals which may be intentionally or unintentionally added to the food.

Biological hazard Living organisms and various microbiological agents like bacteria, molds in the food.

Physical hazards in fruits and vegetables

Material	Sources
Glass	Bottles, jars, light (bulbs), fixtures, utensils, gauges
Wood	Field sources, pallets, boxes
Stones	Broken teeth, fields, buildings
Insulation	Building material
Plastic	Packing, pallets, equipment

- Identify possible physical hazards along the production chain.
- Implement proper practices and counter measures and create awareness and responsibility among workers.

Source: https://agritech.tnau.ac.in/agricultural_marketing/agrimark_Agribusiness_Food%20safety.html

Physical hazards, in fruits and vegetables

Physical hazards, in fruits and vegetables, include various materials. The examples of few physical hazards are as follows:

- **Glass:** This may come from the various sources like bottles, jar or light bulb, fixtures, utensils, gauges etc.
- **Wood:** Comes from the field or pallets or boxes which are used for packaging of the material.
- **Stones:** Food may have stones from sources like broken teeth, fields or buildings etc.
- **Insulation:** This is from building materials
- **Plastic:** It is the packing, either in pallets, comes from various equipments etc.

These are the various sources from which physical hazards may come into the fruits and vegetables. So, we have to identify the possible physical hazard along the products and chain and implement proper practices and counter measures and create awareness and responsibility among the workers to ensure that the commodity is free from any such physical hazards.

Chemical hazards in fruits and vegetables

- It can pose a serious health hazard if they contaminate fresh fruit and vegetables in significant concentrations.

Naturally occurring chemical	Potential health risks for humans
Allergens (e.g. Weeds, peanuts)	Allergenic reactions
Fungal toxins (Mycotoxins; aflatoxins) Phyto haemagglutinin	Multiple poisonings (Acute or chronic)
Alkaloids	Multiple poisonings (Acute or chronic)

- Make minimal and correct use of chemical additives (e.g. agrochemicals, processing and treatment agents, packing additives, pest control agents, antibiotics).




Source: https://agritech.mau.ac.in/agricultural_marketing/agrimark_Agribusiness_Food%20safety.html

Chemical hazards

Chemical hazards may be found in fruits and vegetables and they can pose a serious health hazard if they contaminate fruits and vegetables in significant concentrations. There are many commodities there are naturally occurring chemicals like allergens found in the weeds or peanuts. Allergic reactions sometimes lead to severe and serious health problems. Similarly, multiple poisoning either acute or chronic may be caused by fungal toxins present in the materials like mycotoxins, aflatoxin or phyto-haemagglutinin. Alkaloids present in the food material also cause on multiple poisoning, either acute or chronic.

There should be minimal and correct use of chemical additives. The thumb rule is to reduce chemicals during processing as far as possible or use of chemical in any food may be avoided. However necessary minimum possible concentration of chemical to be allowed in agrochemicals, processing and treatment agents, packing additives, pest control agents and antibiotics etc.. If these chemicals are used in excessive quantity or they readily remains in the food material and may induce a potential health hazard.

Biological hazards in fruits and vegetables



VISIBLE Biological HAZARDS in FOOD

INVISIBLE (MICROBIOLOGICAL) HAZARDS IN FOOD

- Bacteria
- Fungi (Yeasts and moulds)
- Parasites (Protozoans and helminths)
- Viruses

The primary sources of microbial contamination of fresh fruits and vegetables are

- Untreated manure / faeces or municipal biosolids and sewage fluids)
- Contaminated water (agricultural and processing water)
- Contaminated soil, dust, surroundings and handling equipment
- Poor sanitary practices

Source: https://agritech.tnau.ac.in/agricultural_marketing/agrimark_Agribusiness_Food%20safety.html

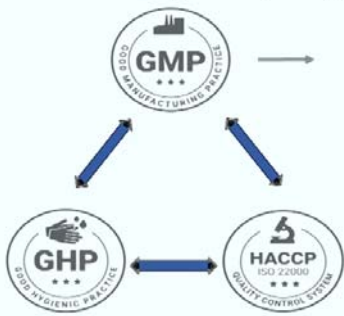
Biological hazards in fruits and vegetables

Similarly, biological hazards in fruits and vegetables may include contamination with bacteria, fungi like yeast, and molds or parasites like protozoa and helminthes or viruses. So, the primary sources of microbial contamination are fresh fruits and vegetables are as follows:

- *Untreated manure or faeces or municipal biosolids and sewage fluids* are accumulate by the plant if not treated properly. The contaminant through the plant comes into the fruits or vegetables.
- If *contaminated water* is used either in the agricultural field or for processing. The contaminated water will be another source of biological hazard.
- *Contaminated soil, dust, surroundings, and poor handling of equipment.*
- *Poor sanitary practices* in the field as well as in the processing plant or where the equipment or the material or where it is being handled.

Food Safety Management Systems

Food safety and quality can be ensured through



- Proactive steps to ensure that products are safe.
- Eliminate contamination and false labelling, thereby protecting the consumer from being misled.
- Helps to refine compliance and performance.
- To identify potential sources of risk .
- Steps to minimise the risk of contamination.
- Ensures that all persons who handle food have good hygiene practices.



Food safety management

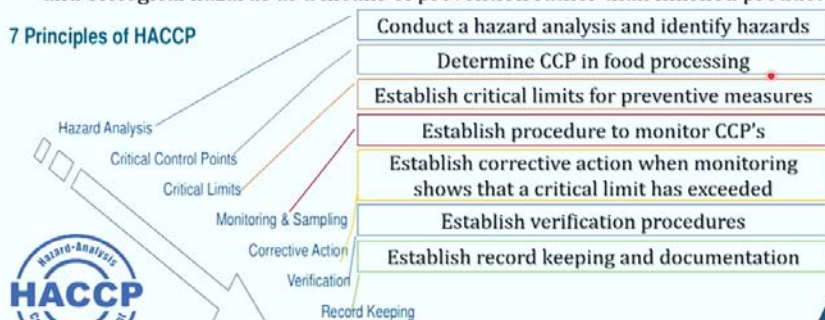
The food safety management system includes food safety and quality can be ensured through implementing of proper *Good Manufacturing Practices (GMP)*, *good hygienic practices (GHP)* and *Hazard Analysis and Critical Control Point (HACCP)*. GMP ensures that products are safe, it eliminates contamination and false labeling, thereby protecting the consumer from being misled.

GMP also helps to refine the compliance and performance. GHP and HACCP are used to identify potential sources of risk, they are the steps to minimize the risk of contamination. It ensures that all persons who handle the food have good hygienic practices or they absorb good hygienic practices.

Hazard analysis & critical control point

HACCP is a systematic preventive approach to Food Safety that addresses physical, chemical and biological hazards as a means of prevention rather than finished product inspection.

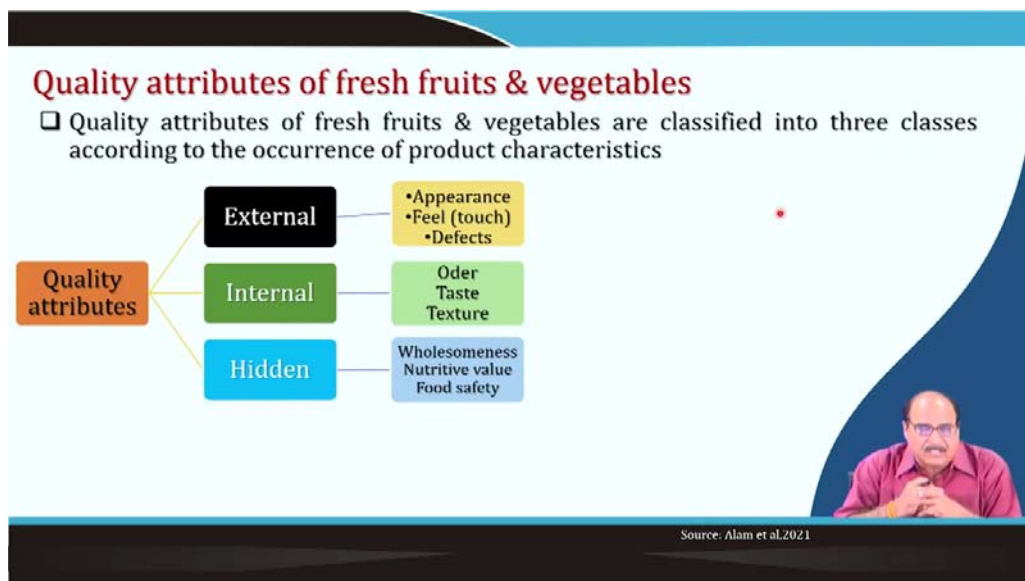
7 Principles of HACCP



Hazard Analysis and Critical Control Point (HACCP).

As previously mentioned, hazard is a systematic preventive approach to food safety that addresses physical, chemical and biological hazards as a means of prevention rather than finish product inspection. There are seven chronological steps of HACCP is commonly known as 7 principles of HACCP, which includes

1. Hazard analysis i.e conducting a analysis and identify the potential hazards
2. Determining the CCP. The critical control point in the food processing is crucial in value chain.
3. Establishing critical limit for preventive measures
4. Establishing a procedure to monitor that CCP.
5. Establishing a corrective action that is when monitoring shows that a critical limit has exceeded. If it has not been followed or implemented properly then what should be corrective action
6. Finally establish verification procedure that whether CCPs are in proper order in value chain, are properly monitoring is in force or not
7. Documentation and recording of everyday procedure and easy retrieval of the data.



Quality attributes of fresh fruits and vegetables

As far as the quality attributes of fresh fruits and vegetables are concerned, they can be classified into three groups according to the occurrences of the product characteristics like it may be external quality attribute, internal quality attributes or hidden quality attribute.

External quality means appearance, feel, touch or such other defects and it can be measured either by visual evaluation of size, shape, gloss and colour or there are visual guides and with the help of colorimeters.

Quality attributes of fresh fruits & vegetables

Quality attributes of fresh fruits & vegetables are classified into three classes according to the occurrence of product characteristics

Quality attributes	Characteristics	Measurement of quality attribute
External	•Appearance •Feel (touch) •Defects	Mostly qualitative and subjective evaluation by smelling Instrumental methods (gas chromatography)
Internal	Oder Taste Texture	Oral tasting (sweetness, bitterness, sourness etc) Technical quantification of taste compounds (HPLC)
Hidden	Wholesomeness Nutritive value Food safety	Texture profile (Firmness, tenderness, mouthfeel etc.) - Measured by applying force to the produce

Source: Alam et al.2021

Manual evaluation of texture can be done by mechanical texture analysis or evaluation of absence of different defects or deterioration of color. External quality parameter can also be measured by mechanical methods like ultrasound.

Internal quality like order, taste, and texture can be qualitative or subjective methods. These include sensory methods as well as instrumental methods. Instrumental methods are like gas chromatography, are becoming more popular nowadays than oral testing or sensory evaluation of sweetness, bitterness, sourness. Furthermore, technical quantification of the taste compounds using HPLC can be done. Texture profile like firmness, tenderness, mouthfeel can be measured by applying the force to the produce and analyzing that how much force is required to break or rupture the product.

Quality attributes of fresh fruits & vegetables

Quality attributes of fresh fruits & vegetables are classified into three classes according to the occurrence of product characteristics

Quality attributes	Characteristics	Measurement of quality attribute
External	•Appearance •Feel (touch) •Defects	Described as "freshness" "produce integrity"; Sanitary Component - how clean / hygienic the product is.
Internal	Oder Taste Texture	Content of macro, micronutrients & phytochemicals.
Hidden	Wholesomeness Nutritive value Food safety	Examination of food items with regard to their pathogenic microbial load, content of chemical contaminants or presence of foreign matter.

Source: Alam et al.2021

Wholesomeness and nutritive value are food safety attributes which are considered as a **hidden quality attributes** they can be analyzed by laboratory methods and instrumental method for determining micronutrients and phytochemicals.

There are standard setup procedures and protocols which can be used to determine their antigenic microbial load content of chemical contaminants. The presence of foreign matters should be analyzed.

Technologies for non-destructive continuous quality monitoring		
Methodology	Technique being used	Components
Optic	✓ Image analysis	✓ Size, shape, colour,
	✓ Reflectance, absorption reflectance spectroscopy	✓ External defects ✓ Internal components, colour
	✓ Laser spectroscopy	✓ Firmness, visco-elasticity, shape
X-ray	• X-ray image and CT	• Internal cavity and structure, ripeness
Mechanics	✓ Vibrated excitation	✓ Firmness, visco-elasticity, ripeness
	✓ Sonic	✓ Firmness, visco-elasticity, internal cavity, density, ✓ Sugar content
	✓ Ultrasonic	✓ Internal cavity and structure, firmness, ✓ Tenderness
Electromagnetic	• Impedance	• Moisture content, density, sugar content, • Density, internal cavity
	• MR/MRI	• Sugar content, oil, moisture content, • Internal defect and structure

Technologies for non-destructive continuous quality monitoring

There are some non-destructive methods for continuous quality monitoring for fruits and vegetable. These methods include optic, X-ray mechanical method and electromagnetic method.

1. **Optic method:** Determination of the size, shape, color, reflectance and absorption can be achieved by Image analysis. It can be also be used to find out if there is any external defect in the commodity.

Similarly, **reflectance spectroscopy** can be used for internal component analysis and color. **Laser spectroscopy** can be used to find out firmness and visco-elasticity for various commodities.

2. **X-ray mechanics: X-ray image and CT:** can be used to find out internal cavity and structure, and degree of ripeness of the produce so that the material is fully ripe or less ripe can be found out.

In the **mechanical methods**, vibrated excitations can be used to find firmness, visco-elasticity, ripeness. **Sonic method and ultrasonic** method can be used again to find firmness, visco-elasticity as well as the internal cavity, density, sugar content, and tenderness.

3. **Electromagnetic methods:** These are used to find impedance which is used to determine moisture content, density, sugar content and internal cavity. Similarly, MRI can be used to find out sugar content, oil content, moisture content or internal defect and internal structure of the material.

Optical methods

□ Optical properties are based on reflectance, transmittance, absorbance, fluorescence or scattering of light.

- **Time-resolved reflectance spectroscopy**
 - ✓ Involves the penetration of light in to a diffusive medium which depends on the optical properties of the medium and on the source-detector distance.
 - ✓ In case of fruits and vegetables, the depth of the probe volume is of the same order as the source detector distance.
 - ✓ Information on internal quality of fruits as it measures the bulk properties, not the superficial characteristics alone.
 - ✓ Suitable for grading, maturity determination, and detecting internal defects & in predicting shelf-life.

Source: International et al., 2012

Optical methods

These optical properties are based on reflectance, transmittance, absorbance, or fluorescence or even a scattering of light. So, any of these properties can be used to determine the optical characteristics.

Time-resolve reflectance spectroscopy is a simple setup page which involves the penetration of light into a diffusion medium which depends on the optical properties of the medium and under source detector distance.

In case of fruits and vegetable, the depth of the probe volume is of the same order as the source detector distance. It provides information on internal quality of fruit, as it measures the bulk properties not the superficial characteristics alone. As this method can give information about the internal quality characteristics, it is suitable for grading, maturity determination and detecting the internal defects and in predicting the shelf life of fruits and vegetables.

Optical methods (contd ...)

- **Visible / Near infrared spectroscopy**
 - ✓ 780-2500 nm in electromagnetic spectrum.
 - ✓ Used in fruit firmness measurement and detection of visible blemishes.
 - ✓ Soluble solid content, dry matter, hygroscopicity, firmness, sugar content, acidity, etc.
 - ✓ Evaluate fruit maturity by measuring the skin colour of fruits such as **banana, apple, tomato and mango**.

Source: Baci-Bocanhhegra, 2018

Visible or near infrared spectroscopy includes wavelength ranges from 780 to 25,000 nm in electromagnetic spectrum. It can be used for analyzing various properties such as fruit firmness measurement and detection of visible blemishes, soluble acid content, dry matter, hygroscopicity, firmness, sugar content, acidity etc. Fruit maturity of banana, apple, tomato, and mango can be determined by evaluating the skin color by using visible or NIR spectroscopy.

The application of portable micro near infrared spectroscopy to the screening of extractable polyphenols in the grape fruits is shown here in this figure. This set constitutes a spectroscopic camera, monitor, a micro NIR and an adaptor. The subject (grapes) information this is sent to the micro NIR with an adaptor and micro NIR which reads the spectra and send the information to the laptop or computer where the required data is analyzed by various quantitative method or qualitative method like PCA,. There is some software which analyzes the spectra and give the output as well.

Dynamic methods

❑ **X-ray**

- Maturity and various internal defects in fruits can be analysed by using this technique.
- Freeze damage or internal browning or presence of pits, presence of foreign particles, infested fruits, etc. exhibit changes in density and water content.
- X-ray radiography and x-ray computed tomography (CT scanning) are widely used methods.
- Infestation in apple, pear, peach, cherry tomato and orange were detected successfully.

Source: Veena et al. (2015)

Dynamic method

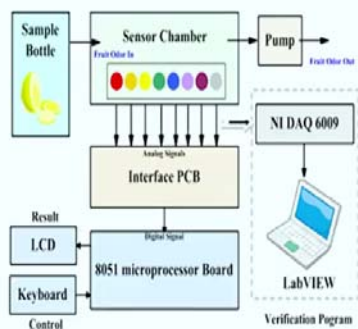
X-ray imaging which is a dynamic method, can detect maturity and various internal defects. For example, freeze damaged or internal browning or presence of pits, presence of foreign particles, infestation which exhibit changes in the density and the water content.

X-ray radiography and the X-ray computed tomography (CT scanning) are widely used method. Infestation in apple, peach, pears, cherry, tomato and orange have been detected successfully using this X-ray imaging.

In the given figure there is a computer, a control panel along with high tension transformers and high tensile insulated cables connected to the X-ray tube head to X-ray sensor. The sensor absorbs the data and pass it on to the computer, where it is analyzed using appropriate software and the output is given.

Mechanical methods

Gas sensor arrays: Electronic nose



Schematic diagram of an E-nose system

- Chemical and electronic sensors which stimulate the functioning of olfactory system.
- Consists of a sensor, data processing unit, software with digital pattern-recognising algorithms and reference library.
- Organic polymers, metal oxides, quartz crystal microbalance and gas chromatography (GC) are the various sensors used.
- The sensors interact with volatile compounds non-selectively to produce signal read by computer called as 'electronic finger print'.



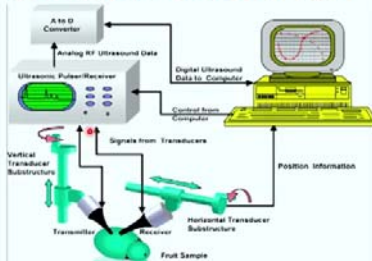
Source: elprocus.com

Mechanical method

Then mechanical method includes *gas sensor array or electronic nose*. Chemical and electronic sensors are there in the electronic nose which simulate the functioning of olfactory system

Electronic nose has various sensors that constitute data processing unit software and digital pattern recognizing algorithm and a reference library. When a sample is given and the volatile components which are present in the sample which are responsible for the flavor: evaporates and these volatile components are sent to the gc chamber. The sensor interact with the volatile compounds non selectively to produce signal and this signal is read by the computer which is called as “electronic finger print” and then these signals are analysed for determination of quality attributes.

Mechanical methods (contd ...)

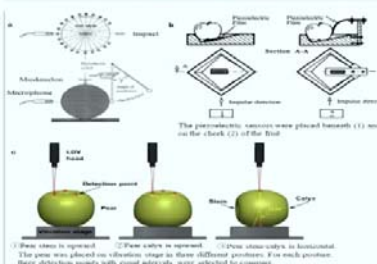


Ultrasonic

- Surface wave transmission techniques.
- Detected density, moisture content and firmness of oranges.

Acoustic impulse response method

- Used to analyse the texture of fruits
- Uses natural frequencies of the intact fruit obtained by recording the sound, produced by hitting the fruit and performs Fourier transformation on signal.



Source: Lakshmi et. Al, 2017

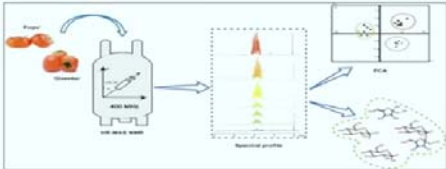
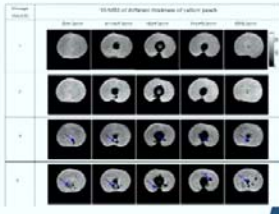
The **acoustic impulse response method** is used to analyze the texture of fruits. It uses natural frequencies of the intact fruit which is obtained by recording the sound, that is produced by hitting the fruit and then by Fourier transformation the signal is analyzed.

Similarly, **ultrasonic** is a surface wave transmission technique. It is used to detect the density, moisture content and firmness of many commodities. In the case of oranges, it had been successfully applied to determine quality attributes.

Electromagnetic methods

❑ Nuclear magnetic resonance techniques

- Absorption of magnetic energy by nuclei placed in an alternating magnetic field.
- Amount of energy absorbed by the nuclei is directly proportional to number of protons present in a sample.
- Determine freeze damage by locating spatial NMR signals.
- Useful in detection of pits in fruits and vegetables.
- Spectra can be interpreted easily.
- Differentiate healthy and freeze damaged oranges.

Source: Zhou et al, 2016

Electromagnetic method

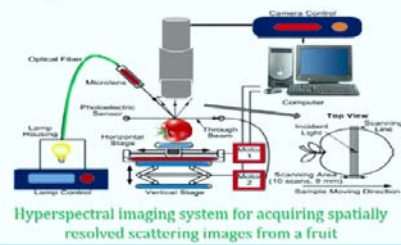
Electromagnetic method which includes **nuclear magnetic resonance techniques** is a absorption of magnetic energy by nuclei placed in an alternating magnetic field. The amount of energy absorbed by the nuclei is directly proportional to the number of protons present in a sample. It determines the freeze damage by locating the special NMR signals and also useful in detection of pits in fruits and vegetables. Spectra can be interpreted easily and can differentiate into healthy and freeze damaged oranges.

The **machine vision** system usually consists of five basic components i.e light source, an imaging unit, an image capture board, computer hardware and software. An automatic machine vision system was industrialized to detect small insects raspberry fruit.

The given figure represents a machine vision system where the commodity (tomato) is placed in front of the light source. The light sources determine the light and are sensed by the camera. The camera sends the signals to the computer CPU where it monitors and analyzes. The image and result is displayed on the monitor.

Hyper-spectral imaging

- The basic principle is that the food reflects, scatters, absorbs and produces electromagnetic energy in different forms at particular wavelengths.
- The reflectance is plotted against the wavelength and the curve is referred to as the spectral signature of that constituent.
- Determine firmness, total soluble solids (TSS) & titratable acidity (TA) of mangoes in the spectral region of 450–998 nm.



Hyperspectral imaging system for acquiring spatially resolved scattering images from a fruit

System contains

- Lighting source
- Sensor which concurrently acquires spectra
- Spectrograph
- Computer to produce the acquired images

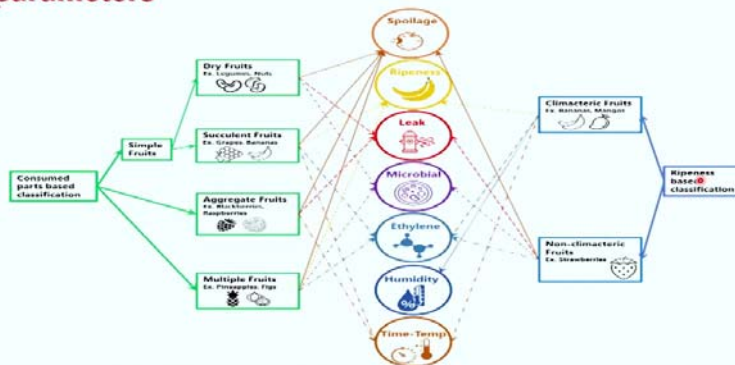


Source: Jin et al. 2009

Hyperspectral imaging

The basic principle of *hyperspectral imaging* is that the food reflects scatters, absorbs and produces electromagnetic energy in different forms at particular wavelength. The reflectance is plotted against the wavelength and curve is referred to as the spectral signature of the constituent. It helps in determining the firmness, total soluble solids (TSS), titratable acidity (TA) of mangos in the spectral regions are 450 to 998 nm. The hyperspectral imaging system contains lighting source sensor which accurately acquires a spectra, spectro graph or computer to produce the acquired images.

Fruit classification hierarchy and its relevance to different freshness parameters



Sensors for freshness detection

Classifications of sensors for monitoring freshness of fruits

- Detects a particular analyte directly from the fruit as an indicator for food freshness.
- Based on reaction-based detection of fruits degradation due to certain freshness parameters such as temperature & time.

Source: Alam et al, 2021

Different freshness parameter

For climatic fruits parameters like ethylene production, humidity and temperature, time maintenance inside the storage environment that may be taken as criteria for the quality determination. Similarly, for dry fruits, spoilage or leak or the microbial contamination can be considered. In the case of multiple fruits that ethylene and microbial contamination or spoilage can be taken as the indicator for freshness. The freshness indicators helps to determine whether the material is good for consumption or has been spoiled.

Sensors for freshness detection

Direct sensors can detect spoilage, ripeness, leak, microbial contamination and ethylene gas production. On the other hand, *indirect methods* detect humidity and temperature. The direct methods detects a particular compound directly from the fruit as an indicator of the food freshness and the indirect methods are good and the based on the reaction based detection of degradation due to certain freshness parameters such as temperature and time.

Sensors for freshness detection (contd ...)

Spoilage sensor

- ✓ Spoilage can be detected using chemical sensors including a pH sensor.
- ✓ The pH of enclosed fruit package changes within the headspace, which can be measured by a pH sensor.
- ✓ Formaldehyde was detected by exploiting the chemical reaction between formaldehyde and primary amines.

Ripeness sensor

- ✓ Sensor reacts with the aromas emitted by ripening fruit.
- ✓ Pears, kiwifruit, melon, mango, and avocado.
- ✓ Different stages of fruit ripeness can be studied using e-nose.

Freshness indicator for guavas packaging

Source: Zhou et al, 2016

In case of *spoilage sensor*, the spoilage can be detected using chemical sensor including pH sensor. The pH of the enclosed fruit package changes within the headspace, which can be measured by using a pH sensor. Formaldehyde can be detected by exploiting the chemical reaction between the formaldehyde and the primary amines.


Then similarly, *ripeness sensor* reacts with the aroma emitted by the ripened fruits like Pears, Kiwi, Melon, Mango etc. And different stages of fruit ripeness can be studied using even e-nose.

Sensors for freshness detection (contd ...)

Colorimetric sensor

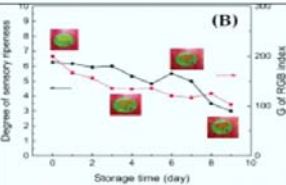
- It was developed that utilize pH indicators based on methyl red to detect aldehyde emission as a marker of apple ripeness.

(A)




Reaction setup for the detection of apple flavour using a sensor label

(B)



Degree of sensory ripeness and RGB index plot vs storage time



Colour changes in sensor label after exposure to apple flavors

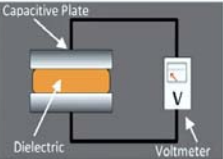
Source: Kim et. al, 2018

Colorimetric sensor utilizes the pH indicator based on methyl red to detect aldehyde emission as a marker of the apple ripeness and this can be used for similar such other fruits. In this figure, the Degree of sensory ripeness and RGB index plot vs storage time relationship is shown. There is a Colour changes in sensor label after exposure to apple flavors and on the basis of these color changes, one can get an idea about its freshness.

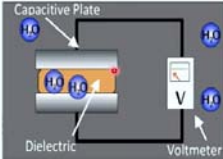
Indirect indicators of freshness or spoilage

Humidity sensor

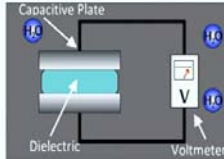
- A capacitive humidity sensor is a type of humidity sensor (i.e., hygrometer) that utilizes change in capacitance to detect relative humidity levels.



Initial setup of capacitive sensor indicating no detectable voltage across the plates



The introduction of water vapor in the atmosphere



Change permittivity of the dielectric because of water vapor, generating a detectable voltage on plates

Source: Kim et. al, 2018

Indirect indicators of freshness or spoilage

Similarly, the indirect sensors like the capacitive *humidity sensor* are a type of humidity sensor (i.e., hygrometer) that utilizes change in capacitance to detect relative humidity levels. The first figure is indicating the initial setup of capacitive sensor indicating no detectable voltage across the plates and then the introduction of water vapor in the atmosphere is shown in the second figure. The change of permittivity of the dielectric because of the water vapor generating a detectable voltage on the plates is displayed in the third figure and that is measured by this sensor.

Time-temperature indicators (TTIs)

- The chemical and physical mechanisms are based on a chemical reaction or physical change, respectively, due to changes in time and temperature.
- Examples of such TTIs include Fresh-Check®, Monitor Mark™, OnVu™, eO®, Timestrip®, Checkpoint®, and Tempix.

Schematic representation of the TTI, (A) Fresh-check, (B) Time strip, (C) Monitor mark, (D) Check point

Source: Alam et al. 2021

Time temperature indicator

Time temperature indicator empowers on chemical and physical mechanisms that are based on a chemical reaction or a physical change respectively due to changes in the time and temperature. There are various TTI indicators available in the market which include Fresh-Check®, Monitor Mark™, OnVu™, eO®, Timestrip®, Checkpoint®, and Tempix.

In monitor mark figure C the ethyl label is completely blocked indicating the freshness. In figure D, if the circle is pink, it indicates spoilage. So, there are various combinations of TTIs by using nano technology and the sensors that are produced can give the desired information.

Traceability and RFID-based sensor system

- RFID technology is used to track and identify the product quality during storage and transport in containers.
- These systems require an RFID tag with an antenna, an RFID scanner, and utilize radio waves to communicate data to a network.
- Active tags allow for real time traceability as they can constantly send out information.
- Freshness sensors are being employed commercially with RFID tags to monitor RH, temperature, light exposure, pressure, and pH of foods.



Food traceability using smartphone and tracking & tracing across the supply chain



Source: Danny Pignini & Massimo Conti

Traceability and RFID based sensor

The traceability and RFID based sensor system indicator is used to track and identify the product quality during storage and transit. These systems require RFID tag with an antenna and an RFID scanner and utilize radio waves to communicate data to the network. These active tags allow the real time traceability as they can constantly send out information. Freshness sensors are being employed commercially with RFID tags to monitor relative humidity, temperature, light exposure, pressure, pH of foods or even during transit they are used to check whether the material is in good condition or not.

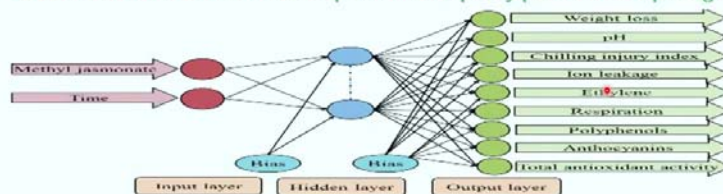
Food traceability using smartphone and tracking and tracing across the supply chain can be achieved by developing an mobile app and displaying the data from RFID on the app. So, this is how the smart apps and cloud storage is being used for traceability

Predictive modelling quality parameters of fruits and vegetables

Artificial Neural Networks (ANN)

- ANN draws on previously gathered information and uses this when analyzing new data input.
- For pattern detection it may make electronic nose applications more powerful for fruit quality analysis.
- Neural network models were used to predict the shelf-life of greenhouse lettuce.
- Using two-stage ANN models, an r^2 of 0.61 could be achieved for predicting the remaining shelf life.

Artificial neural network model for prediction of quality parameters of pomegranate



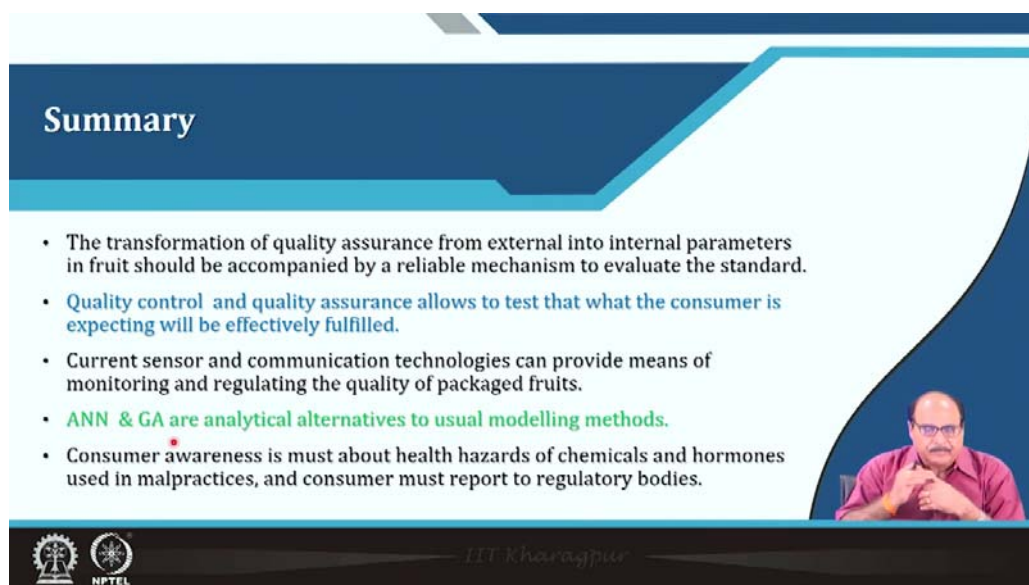
Source: Salehi, F. (2020)

Predictive modeling of quality parameters of fruits and vegetables

Artificial neural network (ANN) is one such model which is mostly used for predictive modeling of quality parameters. ANN draws on previously gathered information and uses this information when analyzing new data point. So, for pattern detection, it may take the make the electronic nose applications more powerful for fruit quality analysis.

So, neural network models are used to predict the shelf life of greenhouse lettuce or any other any such their commodity. So, by using two stage ANN model system models were developed which could predict the shelf life of the fruit.

ANN model system consists of input, output and hidden layer. It could analyze the bias and send it to hidden layer and finally, on the basis of this analysis the model gives output which may be of any particular desired quality like weight loss, pH, calorie, ion exchange, ethylene and respiration etc.



Summary

- The transformation of quality assurance from external into internal parameters in fruit should be accompanied by a reliable mechanism to evaluate the standard.
- Quality control and quality assurance allows to test that what the consumer is expecting will be effectively fulfilled.
- Current sensor and communication technologies can provide means of monitoring and regulating the quality of packaged fruits.
- ANN & GA are analytical alternatives to usual modelling methods.
- Consumer awareness is must about health hazards of chemicals and hormones used in malpractices, and consumer must report to regulatory bodies.

Dr. J. K. Khanna

NPTEL

In summary, transformation of quality assurance from external into internal parameters in fruits should be accomplished by a reliable mechanism to evaluate the standards. Quality control and quality assurance allows to test that what the consumer is expecting will be effectively fulfilled. Current sensor and communication technologies can provide means of monitoring and regulating the quality of the package fruits and vegetables. artificial neural network and genetic algorithm are analytical alternatives to visual modeling methods.

Consumer awareness is must about health hazards of chemical and hormones used in malpractices. The consumer must report this to the regulatory bodies about any malpractice in the value chain or if the commodity or material is not of desired quality and safety standards.

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These are the references for further study. Thank you.