Internal Quality Classification of agricultural produce using Non-destructive Image Processing Technologies (soft X-ray)

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Abstract - A number of non-destructive methods for internal quality evaluation have been studied by different researchers over the past eight decades. Consumers are now more conscious about quality and source of their foods. Attempts made to determine the quality of food materials are numerous, but most of them are destructive in nature. In recent years, non-destructive methods such as X-ray imaging, Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Near Infra red and ultrasound of quality evaluation have gained momentum and considerable attempts have been made to develop them, among these techniques X-ray and computed tomography imaging techniques are few of them which are gaining popularity now days in various fields of agriculture and food quality evaluation. These techniques, so far predominantly used in medical applications, have also been explored for internal quality inspection of various agricultural products non-destructively, when quality features are not visible on the surface of the products. Due to low penetration power and ability to reveal the internal density changes soft X-rays are more suitable to be used on agricultural products. In the present paper the potential of x-ray especially soft x-ray for internal quality classification of agricultural produce has been reviewed.

I .INTRODUCTION

Non-destructive quality evaluation of agricultural products has become a major area of interest for the agricultural processing industry. Researchers have been working to find techniques for evaluating internal quality attributes of agricultural and food products non destructively **G**rowing consumer awareness in the international markets pose stringent quality measures on agricultural produce exported from India.
Quality is the degree of excellence of a product **(Judith *et al.*, 1998)**. The quality of agricultural commodities is characterized based on individual or a combination of various properties, viz. physical, mechanical, optical, sonic, electrical, electro-magnetic, thermal, hydro and aero dynamic, etc. External quality parameters like size, shape, colour, tenderness, and hardness are evaluated based on eye judgment and hand feel. Internal qualities include texture (firmness, crispness, juiciness),nutrition (carbohydrates ,proteins and vitamins) and defects like pest infestation internal cavity ,water core ,frost damage ,rotten are difficult to access by visual appearance hence there is a need for technology that can determine the internal quality parameters of the produce . Still harvesting is largely done manually. Not only are these activities generally monotonous and in some cases bad for the health of those involved; the associated labour costs also have a considerable effect on the prices of the end products. The automatic inspection of quality in the agro-industry is becoming of paramount importance in order to decrease production costs and increase quality standards.

1.1 Non destructive measurement of agricultural produce quality

1.1.1 Fundamentals of computer vision and image processing

The detection of defects, quality control, classification and sorting of the product are some of the major applications of machine vision system. Machine vision systems not only recognize size, shape, colour, and texture of objects, but also provide numerical attributes of the objects or scene being imaged. Image processing and image analysis are recognised as being the core of computer vision **(Krutz, Gibson, Cassens, & Zhang, 2000).**
A computer vision system generally consists of five basic components: illumination, a camera, an image capture board (frame grabber or digitiser), computer hardware and software **(Wang & Sun, 2002).** There are many different sensors which can be used to generate an image, such as ultrasound, X-ray and near infrared spectroscopy. Images can be also obtained using displacement devices and documents scanners. Typically the

image sensors used in machine vision are usually based on solid state charged coupled device (CCD) camera technology with some applications using thermionic tube devices. CCD cameras are either of the array type or line scan type. The process of converting pictorial images into numerical form is called digitisation in this image is divided into a two dimensional grid of small regions containing picture elements defined as pixels by using a vision processor board called a digitiser or frame grabber.

Image processing/analysis involves a series of steps, which can be broadly divided into three levels: low level processing, intermediate level processing and high level processing **(Gunasekaran &Ding, 1994; Sun, 2000).** Low level processing includes image acquisition and pre-processing. Image acquisition is the transfer of the electronic signal from the sensing device into a numeric form. Intermediate level processing involves image segmentation, and image representation and description. Image segmentation is one of the most important steps in the entire image processing technique, as subsequent extracted data are highly dependent on the accuracy of this operation. Its main aim is to divide an image into regions that have a strong correlation with objects or areas of interest. Segmentation can be achieved by three different techniques: thresholding, edge-based segmentation and region-based segmentation. Thresholding is a simple and fast technique for characterising image regions based on constant reflectivity or light absorption of their surfaces. High level processing involves recognition and interpretation, typically using statistical classifiers or multilayer neural networks of the region of interest. These steps provide the information necessary for the process/ machine control for quality sorting and grading.

1.1.2 Non –destructive techniques

In recent years, X-ray based systems have increasingly been used effectively as a research tool for the detection of internal defects in agricultural products. Techniques such as X-ray imaging, Computed Tomography (CT), Magnetic Resonance Imaging (MRI), Near Infra red and ultrasound have been explored for non-destructive evaluation of indicators not visible on the surface of variety of agricultural products. The non destructive methods can be classified into optical, electromagnetic and dynamic methods table 1 is a summary of those techniques and quality components that could be measured with the corresponding techniques.

Table 1. Non –destructive techniques to measure quality factors of horticultural produces.

Principals	**Technique being used**	**Components**
Optics	Image analysis Reflectance ,transmittance and absorbance spectroscopy, laser spectroscopy	Size,shape,colour,external defects,colour.chemical constituents,internal defects Firmness,visco-elasticity,defects,shape
Dynamics	Vibrated excitation Sonic Ultrasonic X-ray image and Computed Tomography	Firmness,viscoelasticity,ripeness Firmness,viscoelasticity,internal cavity density Internal cavity and structure, firmness, tenderness. internal cavity and structure, ,ripeness
Electro-magnetic	Impedence MRI	Moisture content,density,sugar content,density,internal cavity Sugar content, oil, moisture content, internal defect and structure.

(Source: Sang-Ha NOH and Kyu-Hong CHOI)

Nimesh *et al.*, 1993 have developed an image analysis system consisting of an illumination chamber, colour camera, frame grabber, and microcomputer to evaluate the colour of stonefruit. Defects were grouped into four categories: slight defects, more serious defects by sorting Jonagold apples based on the presence of defects using a multi-spectral vision system including four wavelength bands in the visible/NIR range leading to the rejection of the fruit and recent bruises. **(Kleynen *et al*., 2004).** A machine vision system and an algorithm based on ultraviolet imaging was developed by **Al-Mallahi *et al*., 2010** to detect potato tubers on the potato harvester and about 98.79% of the tubers and 98.28% of the clods were detected successfully. **Maja *et al*., 2010** presented a new method for quantifying the apparent micro porosity using Magnetic Resonance Imaging (MRI). The method is based on the differences in magnetic susceptibility between gas-filled intercellular spaces and their environment inside fruit tissues. It was tested at two different magnetic fields (1.5 and 0.2 T) on apple and tomato fruit. The method was validated by comparing the MRI results with estimation of local tissue porosity using X-ray micro tomography experiments.

X-ray imaging is one of the most prominent techniques for medical diagnostics. Besides medical imaging, there are many applications of X-rays such as checking luggage at airport, inspecting industrial components, security etc. Use of X-rays in inspection of agricultural commodity is still in primary stage.

II. X-RAY DETECTION FOR QUALITY CLASSIFICATION

X-ray imaging is an established technique to detect strongly attenuating materials and has been applied to a number of inspection applications within the agricultural and food industries. X-rays are electromagnetic radiation ranging in wavelength from about 0.01 to 10nm. The shorter the wavelength of the x-ray the greater is its energy and its penetrating capacity. The shorter wavelengths closer to and overlapping the gamma rays are called hard x-rays.

X-rays, because of their high energy, can penetrate many objects. However, there is variability in penetration through different materials due to differences in their material properties. Photons in an X-ray beam, when passing through an object, are transmitted, scattered, or absorbed. Intensity of the transmitted photons is attenuated by following equation **(Curry *et al*., 1990)**:

$$I = I_0 \exp(-\mu z)$$

Where I is intensity of attenuated photons, I_0 the intensity of incident photons, μ the linear attenuation coefficient (1/cm) and z is the material thickness (cm) through which the X-ray passes. Radiography seeks to capture the X-ray transmission difference due to differences in material properties in the form of visual contrast in the image. This contrast can be a measure of spatial and quantitative distribution of certain material(s) within a composite of materials.

Electromagnetic waves with wavelengths ranging from 0.1 to 10 nm with corresponding energies of about 0.12to 12 keV are called soft X-rays. Due to low penetration power and ability to reveal the internal density changes soft X-rays are more suitable to be used on agricultural products. **Neethirajan *et al.* (2007 b)** reported that the soft X-ray method was rapid and took only 3–5 s to produce an X-ray image.

2.1 X-ray sources

X-rays are produced when high-energy electrons strike a target material, typically Tungsten. An X-ray tube is similar in design to a light bulb, except that the electrons shedding from the heated filament are subjected to a high voltage, causing them to accelerate and strike the target at high energies. As these high energy electrons decelerate in the target material, electrons of target atoms are first excited to higher energy levels, and then decay to their ground states with the emission of X-ray photons. The size of the target area over which X-rays are generated is called the focal spot size, and has consequences for the characteristics of the imaging system. The X-rays themselves have two characteristics that are important in the operation of the X-ray machine; energy and current. The energy refers to the maximum energy that an X-ray photon can possess when exiting the tube (generally between 20 and 100 KeV for food inspection) and defines the penetrating power of the X-ray beam. The current, measured in mA, is associated with the number of X-ray photons being generated. The power supply has a maximum power (the product of the energy and the current) rating, and a balance is therefore required between the energy and current, which has consequences for the resulting image quality. The result of this power limitation is that most X-ray inspection systems are limited to less than 10 mA of current.

2.2 Detection and imaging

The first X-ray detector was a sheet of paper coated with barium platinocyanide used by Roentgen in 1895. The paper fluoresced when impacted by X-rays, and led to their initial discovery. Since that time, many different materials have been observed to react to the presence of X-rays and have led to many different types of detectors. Modern X-ray inspection units generally fall into one of three categories: film, linescan machines, and direct detection semiconductor materials. Of these, film is the most widely used because of its high resolution and dynamic range. It is used for quality inspection of many food products other than medical and dental purposes.

Conventionally, there are two methods to acquire X-ray image. The first method is that the inspected object is fixed and the linescan sensor is moved with a constant speed within the exposure range of the X-ray source tube. The second method is that both X-ray source tube and linescan sensor are fixed and let the object move through the inspection zone. Taking the quarantine requirement into consideration **Ta et al., 2005** adopted the second inspection method. The schematic layout of the X-ray imaging system is illustrated in Fig. 1.

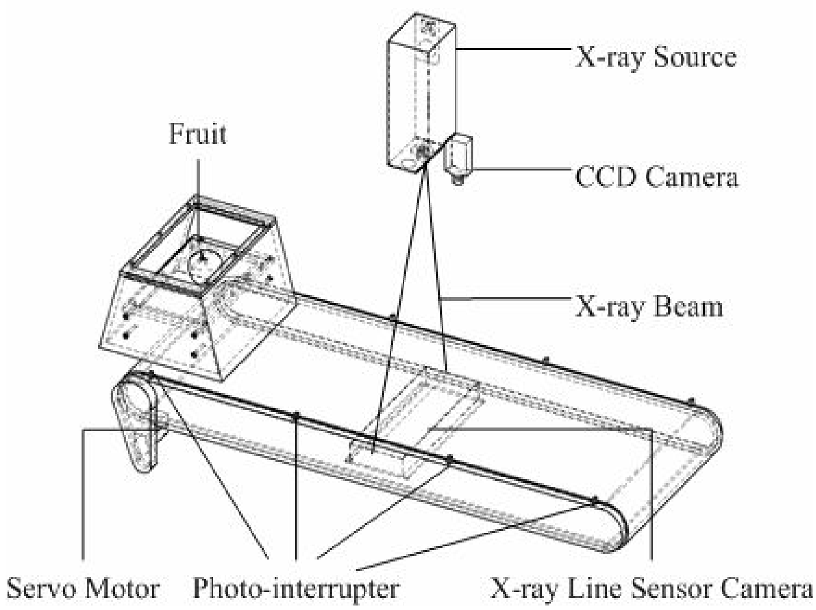

Fig. 1. Schematic layout of the imaging and conveyor system.

Phosphors are a class of luminescent material, which absorb electromagnetic radiation and re-emit it at a longer wavelength. When used as an X-ray detector, the phosphor will absorb X-ray photons and emit visible light photons which are subsequently detected by either photodiodes or CCDs. Some line scan detectors by pass the use of phosphors by using modern semiconductor materials that convert incident X-ray energy directly into an electric current. In a linescan array, hundreds or thousands of detectors, either photodiodes overlaid with phosphor or semiconductor crystals, are placed in a row perpendicular to the direction of sample flow. While the sample moves over the array at a fixed rate, the output of the photodiodes are repeatedly read at a rate that is synchronized to the speed of the sample. The image is then constructed row by row. A third class of X-ray imaging system, commonly known as X-ray fluoroscopy, involves the use of image intensifiers. These devices, which amplify light, are commonly used in low light situations such as night vision. Unlike linescan inspection systems, image intensifiers produce an image that can be observed directly or cast onto a screen. However, image capture applications require coupling to a camera. CCD cameras are generally used for digital image acquisition, forming a real time digital imaging system.

For X-ray imaging, the photocathode is overlaid with a material that fluoresces in the presence of X-rays, converting the incident X-ray photons into visible light. A variation on X-ray linescan imaging that allows three dimensional images is computed axial tomography, or CT imaging. An X-ray source rotates around the sample with detectors positioned opposite the source. Multiple ''slices'' are progressively imaged as the sample is gradually passed through the plane of the X-rays. These slices are combined using a mathematical procedure known as tomographic reconstruction to form a three dimensional image. Helical or spiral CT machines incorporate faster computer systems and advanced software to process continuously changing cross sections. As the sample moves through the X-ray circle, three dimensional images are generated that can be viewed from multiple perspectives in real time on computer monitors.

Gisele *et al*., 2005 have developed an innovative technique based on X-ray scattering applied to classify complex organic matrices of different vegetable oils like corn, canola, soybean, sunflower and olive (extra virgin and others). Understanding foam microstructure formation is important for a priori design and engineering of new biopolymer-based products for both food and industrial applications. **Trater *et al.*, 2005** investigated a non-invasive imaging technology, X-ray microtomography (XMT), for visualization and measurement of microstructural features of biopolymer foams.

Practical application of X-ray imaging in quarantine inspection to prevent propagation of alien insect pests in imported fruits is still unavailable. The first step to identify insect infestation in fruit by X-ray imaging technique is image acquisition. This is followed by the image segmentation procedure, which can locate sites of infestation. Since the grey level of X-ray images depends on the density and thickness of the test samples, the relative contrast of infestation site to the intact region inside a typical fruit varies with its position. To accurately determine whether a fruit has signs of insect infestation **Joe-Air Jiang *et al*., 2008** developed an adaptive image segmentation algorithm based on the local pixels intensities and unsupervised thresholding algorithm for several types of fruit such as citrus, peach, guava, etc. Analyses were performed using the developed algorithm on the X-ray images obtained with different image acquisition parameters. Fruit containing high amounts of water have been deemed unsuitable for X-ray imaging.**En *et al*., 2006** tested the possibility of examining internal injuries of various fruit using digitized X-ray imaging analysis. The digitalized X-ray images showed that this technique can detect injuries caused by *B. dorsalis* at as early as 3 days after implantation of eggs in some fruits.

The X-ray diffraction spectroscopy has been used as an analytical tool for the characterization of minerals that are present in the shells of shellfish as inorganic materials along with biomaterial**. (Ijaz *et al*., 2008).**The pore-size distribution (PSD) has an important influence on the complex gas transport phenomena (O_2 and CO_2) that occur in apple tissue during storage under controlled atmosphere conditions. It defines the apple tissue microstructure that is correlated to many other apple properties. Comparisons among cultivars using multifractal analysis (MFA) to study the multiscale structure of the PSD using generalized dimensions in three varieties of apples (Jonagold, Greenstar, and Kanzi) based on X-ray imaging technology (8.5 lm resolution) showed that, in spite of the complexity and variability of the pore space of the apple samples, the extracted generalized dimensions from PSD were significantly different ($p<0.05$) **(Fernando Mendoza *et al*., 2010)**. **Cheng-Long Chuang *et al*., 2011** presented a new automatic and effective quarantine system for detecting pest infestation sites in agricultural products, e.g. fruits. This work integrated mechanical design, mechatronics instrumentation, X-ray and charge-coupled device (CCD) image acquisition devices, LabVIEW-based analysis and control software, and image diagnosis algorithms into the automatic X-ray quarantine scanner system.

Nachiket *et al*., 2007 used a soft X-ray digital imaging system to acquire radiographs of pecans. The equipment used consists of an X-ray tube, solid-state digital X-ray camera, computer, digital frame grabber, data acquisition and control card, along with appropriate software (Fig. 2). The equipment has an X-ray tube capable of operating from 4 to 50 kVp with maximum current of 1 mA. X-rays generated at a tungsten anode pass through a 127-µm thick beryllium window with a diverging cone angle of 25˚. The X-ray spot at the window exit is a 76 µm×93µm oval. The solid-state digital X-ray camera positioned below the target sample, served as detector. The camera was constructed with a two-dimensional photodiode array of 1024×1024 pixels on 48-µm center-center spacing, giving a detector area of 49.2mm×49.2 mm. A data acquisition and control card was mounted on the computer for X-ray tube control. Peak voltage and current to the X-ray tube were software controlled.

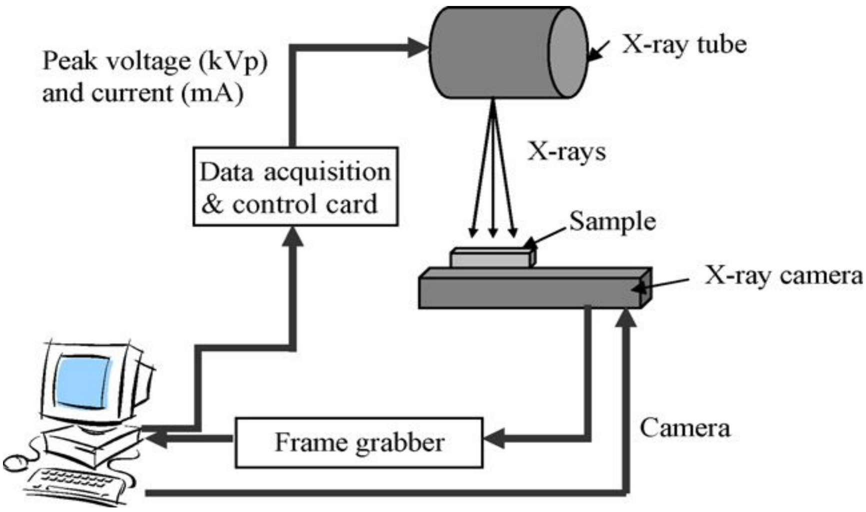

Fig. 2. Schematic of X-ray imaging system.

International conference (JECFI) organized by World Health Organization (WHO), the United Nations Food and Agriculture Organization (FAO), and the International Atomic Energy Agency (IAEA) reported "NO toxicological hazard is observed in any 10 kGy irradiation food**."** in 1981**.** From this report, it became obvious that there is no problem in microbiological safety, and nutriological qualification of irradiated food. The irradiation sterilization is conducted for preventing spices and dry foods from injurious insects, bacteria and rodents in foreign countries instead of chemicals; it is being used for germination control of potatoes in Japan. It is said that the utilization for those purposes are good for environmental conservation. Based on these results, radiation is being indispensable for secure food because of sterilization. From this, a purpose of this study is establishment of technology to detect internal quality by a low energy soft X-ray which is able to be considered as a safety light.

2.3 Image processing by using soft x-ray

Electromagnetic waves with wavelengths ranging from 1 to 100 nm are called soft X-rays. The low penetration power and ability to reveal the internal density changes make soft X-rays suitable to be used for agricultural products. The soft X-ray imaging method scans singulated kernels and determines infestations. This is advantageous as the grain handling and processing company's regulations are based on the number of infested kernels. The method can detect the infestations if the insects are present in the sample or not **(Chithra *et al.*, 2005).**

The soft X-ray method is rapid and takes only a few seconds (3–5 s) to produce an X-ray image. There is a need for an objective and efficient method to detect insect infestations in the incoming grain in commercial grain-handling facilities. Insect infestations in stored wheat affect the chemical characteristics and baking qualities of wheat flour, and insect-infested flours are unacceptable in the baking industry. The efficiency of the soft X-ray method to detect infestations caused by *Cryptolestes ferrugineus* (Stephens), *Tribolium castaneum* (Herbst), *Plodia interpunctella* (Hübner), *Sitophilus oryzae* (L.), and *Rhyzopertha dominica* (F.) in wheat kernels was determined by **Karunakaran *et al*. (2003 b) .** The potential of a soft X–ray method (15 kV and 65 A) to detect internal seed infestations by the rice weevil (*Sitophilus oryzae*) in Canada Western Red Spring wheat was determined in a study conducted by **Karunakaran *et al.*(2003 a).**

Soft X-ray transmission images and X ray CT images can be used for a fruit quality inspection**.** Split-pits of peach fruits could be detected through transmission images in a real time, and information of water content distribution and internal structure of fruit were given by CT images and CT numbers. A total quality evaluation system would be completed when this X-ray imaging information was combined with ultra-violet, visible, infrared, and other region information (**Yuichi *et al*., 2003). Karunakaran *et al*. (2004 b)** also studied the potential of a soft X-ray method to detect infestations caused by *Cryptolestes ferrugineus* (Stephens), the most common stored-grain insect in Canada and also to detect the damage caused to kernels by the red flour beetle, *Tribolium castaneum* (Herbst), in wheat. Hardness is a kernel characteristic that influences both milling and processing characteristics of wheat. It is one characteristic that is used for segregating wheat to meet the needs for various products. Kernel virteousness is a visual marker for hardness and is the characteristic assessed during the grading process. The potential of classifying vitreous and non-vitreous durum wheat kernels, increase-down position, using imaging systems based on real time soft X-rays .The classification accuracies were 76% for vitreous kernels and 82% for non-vitreous kernels at 16% moisture content using the soft X-ray system **(Neethirajan *et al*., 2007 a).**

In order to prevent grain mass and quality losses, rapid methods for early detection of insect infestation of cereal grain during trade and storage are urgently needed. Amongst many options, the soft X-ray method using roentgenograms is one of the most frequently applied. **Jozef *et al*., 2006** showed that when some corrections for working parameters of the equipment used are made and some modification of the digital image analysis introduced, the soft X-ray method is suitable for accurate detection of granary weevil eggs laid in wheat kernels if at least 5 days after oviposition have elapsed.

Dual energy X-ray imaging technique is an alternative to simple transmission X-ray imaging. The former has the ability to reveal the internal density changes of a scanned object by exploiting differences in how the scanned material interacts with X-rays at different energies. **Neethirajan *et al*., 2007** studied the feasibility of dual energy X-ray image analysis to classify vitreousness in durum wheat at 12, 14 and 16% moisture content (m.c.) Neural network classifiers correctly classified vitreous and non-vitreous kernels with 93% accuracy. The statistical classifiers provided 89% accuracy for vitreous and non-vitreous kernels. **Nachiket *et al*., 2007** used soft X-ray digital imaging for non-destructive quality evaluation of pecans. Pecan nutmeat weight was estimated with an error of less than 10% from images taken at 35 kVp–0.75 mA, 40 kVp–0.5 mA, and 45 kVp–0.5 mA. Defects and insects were clearly differentiated in X-ray images after applying contrast stretching or high-frequency emphasis techniques.

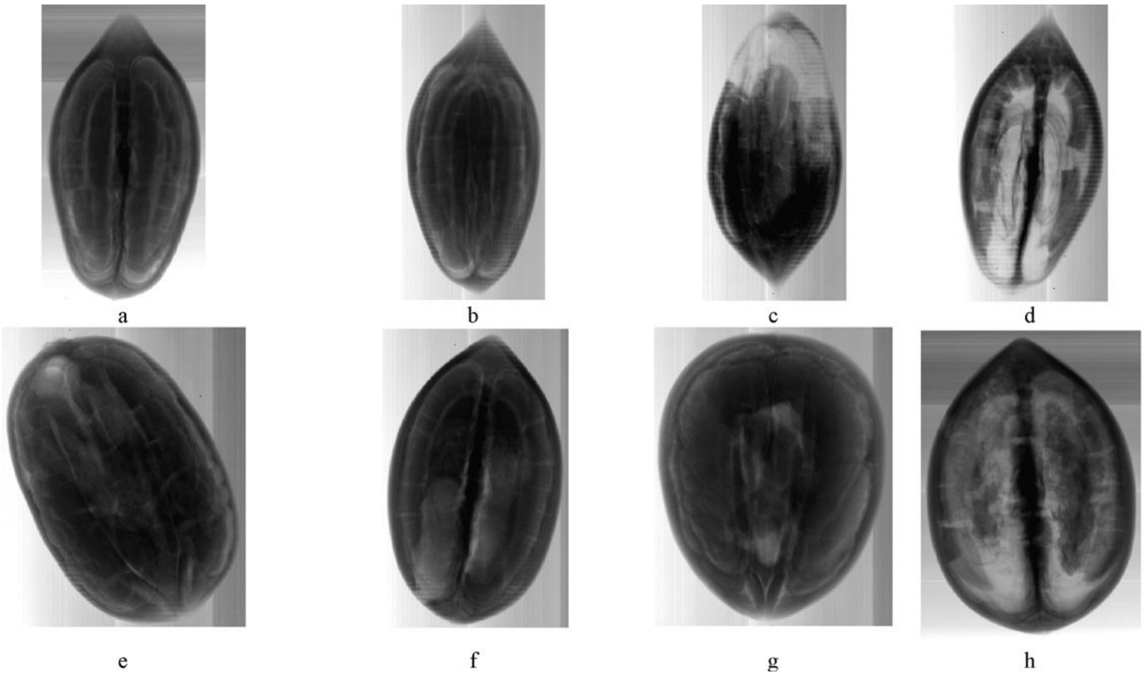

Fig. 2. X-ray images of some pecans with different visible attributes. (a) Good nut; (b) good nut with shucktight; (c) nut with mechanical damage; (d) nut with shriveled nutmeat; (e) insect damage to one cotyledon from inside; (f) visible insect hole; (g) insect damage and insect; (h) hollow nut.

Sprouted wheat kernels adversely affect bread and pasta making quality, thus lowering the grade and value to millers, bakers and grain dealers. **Neethirajan *et al.*, 2007** used soft X-ray system for detecting the sprouted wheat kernels. White specks were observed in all the sprouted kernel X-ray images. A four-layer back propagation neural network model correctly classified 90% and 95% of the sprouted and healthy kernels, respectively. Statistical classifier correctly identified 87% and 92% of the sprouted and healthy kernels, respectively.

III. ADVANTAGES

If more than one soft material has to be distinguished from the surrounding area it may be advantageous to image over a range of x-ray energies.

Table 2. Summary of soft x-ray image processing applications for food quality evaluation

Commodity	**Operating parameters**	**Application**	**References**
Wheat kernels	15 kV potential and 65 µA current for 3 to 5 s.	Detection of infestation sites	Karunakara *et al.* (2004)
Durum wheat	17 kV potential and 65 A current for 3–5 s.	Classification of vitreousness	Neethirajan *et al.* (2006)
Peach fruits	40-100 KV and 0.1-3.0 mA	Internal Quality Detection	Yuichi *et al.*(2003)
Pecans	35 kVp–0.75 mA, 40 kVp–0.5 mA, and 45 kVp–0.5 mA.	Quality determination	Kotwaliwale *et al.*(2007)
Wheat grain	20 kV and 60 mA for 120 s.	Detection of granary weevil	Fornal *et al.*(2006)
Wheat grain	15 kV potential and 65 µA for 5 sec.	Detect Infestations	Karunakaran *et al.*(2003)

Wheat kernels	13.5 kV and 185 lA.	Detection of sprouted wheat kernels	Neethirajan *et al.*(2007)
Wheat Kernels	15 kV potential and 65 mA current for 3–5 s.	To detect infestation by Red Flour Beetle	Karunakaran *et al.*(2004)

The reviews suggest that there is not published work on complete automated machine vision system to grade fruits or vegetables based on internal blemishes and colour as an integrated system.

IV. CONCLUSION

The adaptation of Image Processing for quality evaluation of agricultural produce is the area of greatest potential technology, as analysis can be based on a standard requirement in already automated controlled conditions. X-ray based imaging techniques are powerful tools for non destructive internal quality evaluation. The international markets for important agricultural produce are huge and growing, to conquer and to sustain these markets, there is a need for export of high quality products with no internal defects. The currently practiced methods such as sensory evaluation, colour sorting, size grading, and similar ones cannot effectively address the classification of internal blemish free whole produce. Nevertheless, necessity has motivated a considerable research effort in this field spanning many decades Many researchers have devoted considerable effort towards the development of machine vision systems for different aspects of quality evaluation and sorting of agricultural products. As a result, new algorithms and hardware architectures have been developed for high-speed extraction of features that are related to specific quality factors of agricultural produce. The low penetration power and ability to reveal the internal density changes make soft X-rays suitable to be used for agricultural products. Harmful effects of X-rays are definitely a cause of concern while using these techniques, but properly designed shielding can prevent human exposure. Improvements in technology have allowed X-ray detection of internal defects that were not possible in the past. These improvements can be expected to continue into the future.

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