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ORIGINAL ARTICLE

Nondestructive methods for quality evaluation of livestock products

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Abstract The muscles derived from livestock are highly perishable. Rapid and nondestructive methods are essential for quality assurance of such products. Potential nondestructive methods, which can supplement or replace many of traditional time consuming destructive methods, include colour and computer image analysis, NIR spectroscopy, NMRI, electronic nose, ultrasound, X-ray imaging and biosensors. These methods are briefly described and the research work involving them for products derived from livestock is reviewed. These methods will be helpful in rapid screening of large number of samples, monitoring distribution networks, quick product recall and enhance traceability in the value chain of livestock products. With new developments in the areas of basic science related to these methods, colour, image processing, NIR spectroscopy, biosensors and ultrasonic analysis are expected to be widespread and cost effective for large scale meat quality evaluation in near future.

Keywords NIR spectroscopy · Colour · Meat · Grading · Electronic nose · Biosensors

Introduction

Quality control and monitoring is essential part of any food industry. Consumers' expectations for lower price and consistent quality necessitate the need for development of reliable instruments for both assessing quality and pricing. Meat quality is mainly affected by different processes that occur during the growth of the animal and after slaughter. The colour, tenderness, juiciness, and flavor of meat are important factors that affect consumer's evaluation of meat quality and influence their decision relative to making a repeated purchase. The objective of determining the meat quality is to offer to the consumer wholesome, tasty and safe meat at a reasonable price. Evaluation of meat quality is also critical for preparation of good quality meat products.

Nondestructive methods for determining composition and quality include colour measurement, computer image processing, visual and NIR spectrometry, hyperspectral imaging, x-ray imaging, ultrasound, Nuclear magnetic resonance imaging (NMRI), e-nose and biosensors. These methods have the advantage of being nondestructive, fast, inexpensive (after development), and are considered suitable for online determination of many parameters simultaneously. These methods are thus reviewed critically for stimulating further research.

Colour measurement and computer image analysis

Among the properties widely used for analytical evaluation of any material, color is unique in several aspects. While every material can be said to possess a specific property such as mass, no material is actually colored as such. Colour is primarily an appearance property attributed to the spectral distribution of light and, in a way, is related to some source of radiant energy (the illuminant), to the object to which the color is ascribed, and to the eye of the observer. Without light or the illuminant, color does not exist. The property of an object that gives it a characteristic color is its light-absorptive capacity. Meat purchasing decisions are influenced by color and more than any other

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quality factor because consumers use discoloration as an indicator of deterioration of freshness and wholesomeness.

Mancini and Hunt (2005) listed computer vision, instrumental colour analysis (colorimeters and spectrophotometers) as instruments for meat colour measurement. Colorimeter is the most common device used to measure color. A colorimeter produces a measurement in three numbers called tristimulus values. The values are the amount of primary colors in the coating red (X), green (Y), and blue (Z). Colour is also measured in terms of L (lightness), a (redness) and b (blueness) values and/or Hue (H), Intensity (I) and saturation (S). All systems of colour measurement are mathematically interrelated.

Rosenvold and Andersen (2003) observed that the early post mortem temperature rise plays crucial role in colour and colour stability. Increase in the early post mortem temperature and the pH decline were observed in pigs subjected to pre-slaughter stress. But these effects were absent when pigs were fed with the experimental diet. Mancini et al. (2005) showed that exclusion of oxygen and the addition of low concentration of CO minimized beef marrow discoloration compared with high-oxygen modified atmosphere packaging.

Computer vision technology offers great advantages in evaluation of meat colour as the image can be segmented using software and other soft computing methods such as neural network models can be combined in analysis and interpretation of this highly subjective data. Lu et al. (2000) used image processing and back propagation algorithm of neural networks for evaluation fresh pork lion colour. Developments in image processing techniques for food quality evaluation using computer vision were reviewed by Du and Sun (2004) and Brosnan and Sun (2004). Faucitano et al. (2005) used Computer image analysis (CIA) for the quantitative description of marbling fat and assessed the contribution of marbling characteristics to variations in pork eating quality. Koke and Steele (2002) patented an apparatus with a machine vision system arranged to scan or view by acquiring dimensional, volume, shape or type, or meat quality or grading information for packing meat cuts to divert the meat cut to respective packing station. From Indian perspective, the colour, machine vision and image analysis are being studied in ICAR and CSIR laboratories with few technologies commercialized for grading fruits and finding maturity level of fruits. Rapid technological progress in electronics, communication and information technology fields pave way for affordable digital cameras and instrumentation for wide spread use.

NIR spectroscopy

The use of near-infrared (NIR) and visual spectroscopy is rapid and often nondestructive for measuring the composition of biological materials. It works on the principle of absorption, reflection, transmission and/or scattering of light in or through a food material following the Beer Lambert law. Now various NIR spectrometers are available and are being used commercially. Absorption or reflectance of light in known range of wavelengths are measured and correlated with various quality parameters of food material. The configuration of NIR spectrometer is shown in transmittance mode is shown in Fig. 1 and in reflectance mode is shown in Fig. 2. This configuration is same for majority of spectrometer measuring changes in radiation energy. NIR spectroscopy in conjunction with chemometrics can be used to determine all constituents (proteins, fat, sugars etc.) of food products simultaneously.

Prieto et al. (2009) presented a comprehensive review on use of NIR spectroscopy for predicting meat chemical composition, technological and sensory quality parameters of meat and meat products. Prieto et al. (2006) reported that several biochemical parameters such as crude protein, gross energy, ether extract and dry matter in oxen meat have been calibrated successfully in NIR wavelength range but myoglobin, collagen and ash content showed a poor predictability. Hoving-Bolink et al. (2005) found positive correlation of intra-muscular fat content in early post mortem while drip loss prediction was not successful. Prieto et al. (2008) successfully differentiated between beef of adult and young cattle by scanning the homogenized meat in 1100–2500 nm wavelengths. Their findings were mainly based on differences in the intramuscular fat and water content. Gaitán-Jurado et al. (2008) found that the proximate analysis using NIR spectroscopy is better and near to actual in homogenized sample compared intact sample mainly because of uniform distribution of fat and protein after homogenization.

Grimes et al. (2008) reported the use of hyper spectral imaging apparatus for predicting 14-day aged beef tenderness from 2-day postmortem scans. Their model predicted

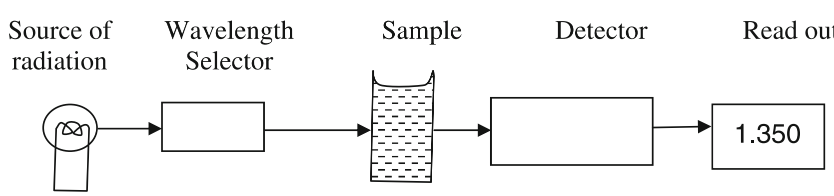

Fig. 1 Configuration of NIR spectrometer in transmittance mode

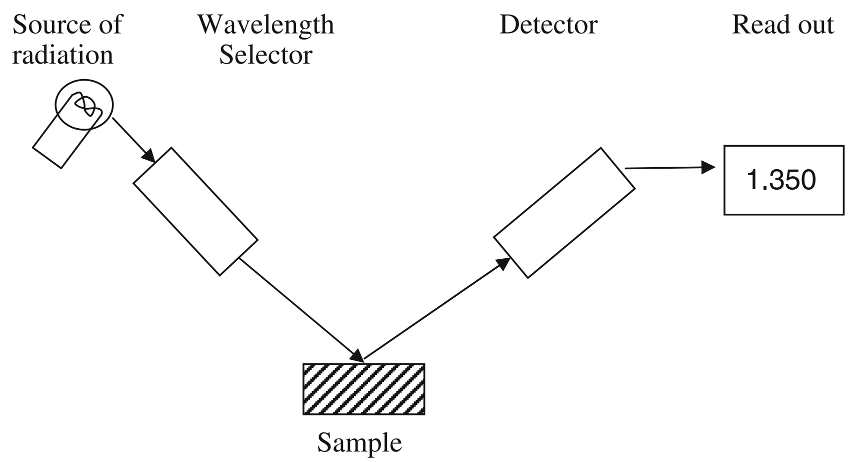

Fig. 2 Configuration of NIR spectrometer in Reflectance mode

three tenderness categories (tender, intermediate, tough) with 77.1% accuracy, and two tenderness categories (acceptable, tough) with 93.7% accuracy. Andrés et al. (2007) used NIR spectroscopy to predict the overall acceptability or texture profile of extreme samples from consumer point of view which may help in proper pricing based on the quality level of lamb meat.

Chao et al. (2001) reported possibility of using optical spectral reflectance and multi–spectral image analysis of chicken hearts for diseases detection. Dey et al. (2003) established a procedure for differentiating normal and septicemia/ toxemia (septox) affected chicken using spectral measurements and neural network classification of the spectral data after principal component analysis (PCA) with an accuracy of 96% and correlation coefficient of 1. In another study, Hsieh et al. (2002) explored the feasibility of using spectroscopy to separate septicemic livers from normal livers and the the classification accuracy was 98% for normal and 94% for septicemic livers. The NIR spectroscopy could be easily used in Indian milk industry for proximate composition analysis.

Biosensors

Biosensors are emerging as attractive instrumentation solutions for rapid detection of food borne pathogens, toxins, pesticide and drug residues, heavy metal ions in food items. Biosensors are also used for determining the freshness of some livestock products. Biosensors offer fast response with high sensitivity which is crucial for food safety from pathogens. For livestock products, majority of research efforts are focused on pathogen detection and optical biosensors are better suited for pathogen detection due to their sensitivity and fast response. Bosch et al. (2007) and Passaro et al. (2007) listed the optical biosensing transducers which could be based on Mach-Zehnder and Young interferometers, microdisk and microring resonators, hollow and antiresonant waveguides, and Bragg gratings using phenomena such as absorption, reflection, surface plasmon resonance (SPR), fluorescence, interference. Many of these sensor platforms demonstrated the proof-of concept by testing with pure bacterial cultures or toxins; however, only a handful of those were tested thoroughly with real-world food samples for their ruggedness, robustness, sensitivity, and cross-reactivity. A comparison of different features of a few optical biosensors used for pathogen detection in meat products is given in Table 1.

Yano et al. (1995) assessed both bacterial spoilage and aging of stored meat using two-line flow injection analysis (FIA) biosensor with putrescine oxidase immobilized electrode for measuring putrescine,cadaverine and a xanthine oxidase immobilized electrode as detectors for measuring hypoxanthine and xanthine. Another potential application of biosensors is assessment of freshness of fish. Watanabe et al. (2005) used xanthine oxidase based biosensor for freshness of sashimi fish by measuring colour change of thiazole blue. Fillit et al. (2008) and Mitsubayashi et al. (2004) found flavin-containing monooxygenase type-3 (FMO3) based biosensors to give good quantitative indications of trimethyl amine with high sensitivity. Frébort et al. (2000) assessed fish freshness in terms of putrescine and histamine using amine oxidase based flow biosensor. Ghosh et al. 1998 used conducting electrodes immobilized with xanthine oxidase, nucleoside phosphorylase and nucleotidase enzymes for measuring ATP degradation products, hypoxanthine, inosine and inosine monophosphate metabolites in fish tissue.

X-ray imaging and computer tomography

X-rays, because of their high energy, can penetrate through many objects. However there are differences in penetration

Table 1 Features of optical biosensors used for pathogen detection in meat products

Pathogen	Bio component	Principle	Detection limit	Analysis time	Reference
E. coli O157:H7	Antibody	Immuno magnetic separation+chemi luminescence	102 CFU/ml	1.5 h	Liu et al. 2001
	Antibody	Fluorescence	5.23×10^2 CFU/g	25 min	Demarco and Lim, 2002
	Antibody	Fluorescence	1 CFU/ml	4 h	Geng et al. 2006
S. enteridis	Antibody	Binding inhibition	10^4 CFU/ml	10 min	Morgan et al. 2006
Listeria monocytogenes	Antibody	Fluorescence	4.3×10^3 CFU /ml	20 h	Geng et al. 2004
	Antibody	SPR	2×10^6 CFU/ml	–	Nanduri et al. 2007
	Antibody	Binding inhibition	5.4×10^7 CFU /ml	–	Kim et al. 2007
	Antibody	Binding inhibition	5×10^5 CFU/ml	–	Nanduri et al. 2006
S. typhimurium	Antibody	SPR	107 CFU/ml	5.5 h	Meeusen et al. 2001

through different materials due to the differences in the material properties. Photons in an X-ray beam, when pass through a body, are either transmitted, scattered or absorbed. Dual energy X-ray absorptiometry (DXA) is becoming a more frequently used technology in farm animal research in order to study the changes in the body composition of live animals and correlate it to carcass quality. Scholz et al. (2007) used DXA of pigs at two different locations using two different instruments yielded a close relationship between both in vivo and carcass DXA fat and lean measurements and the reference data (R^2 values ranged from 0.545 to 0.839). Brienne et al. (2001) used DXA for assessment of meat fat. The R^2 values were higher when the data sets were analyzed separately for each location.

Mitchell et al. (2003) reported that DXA can predict the body composition of pigs. Mercier et al. (2006) used DXA to estimate the dissected composition of lamb carcasses.

Müller et al. (2005) used x- ray technology for online analysis of fat in ground frozen and fresh meats of different animals. Chen et al. (2001) developed a multi resolution-analysis-based local contrast transform using wavelet theory and applied it to deboned poultry inspection using x-ray images. Karamichou et al. (2007) used X-ray computer tomography assessment of traits to help in genetic improvement of carcass quality in hill sheep. These studies show the potential of x-ray for online inspection systems and quality improvement.

Ultrasonic analysis

Acoustic waves are propagated through materials as perturbations in their physical structure. Hence, acoustic properties of a materials can be correlated to its macroscopic composition and structure. This is termed as mechanical spectroscopy and used to measure small deformations in rheological properties at low frequencies. However, ultrasonic waves with higher frequency can reveal valuable information in meat.

Ultrasonics can have frequency from 20 kHz to 10 MHz for instrumentation in foods. Ultrasonic waves are mechanical waves which are a series of mechanical disturbances that propagate as stresses and strains in the physical bonds of the material. Thus absorption or speed of transmission of these waves depends on the nature of bonds and masses of molecules present in material and thus can through light on composition. This low powered ultrasonic waves should be distinguished from high powered ultrasound used for homogenization and cell disruption. The advantages of ultrasonics are easy and quick measurement, applicability to optically opaque food materials and easy adaptability for automated process control. A simplified equation relating material properties with velocity of sound is given as Eq. 1.

$$c^2 = \frac{1}{\kappa\rho} \quad (1)$$

where c is the ultrasonic velocity, ρ is the density and κ is the adiabatic compressibility. More detailed theory and information on experimentation is also available from Coupland and McClements (2001).

Ghaedian et al. (1997) observed that the ultrasonic velocity of the fillets of Atlantic cod (*Gadus morhua*) varied between 1575 and 1595 m s^{-1}, decreasing linearly with increasing moisture content. Benedito et al. (2001) used variation in ultrasonic velocity at two different temperatures to predict chemical composition of fermented sausages with explained variance of 99.6% for fat, 98.7% for moisture and 85.4% for protein plus others. Mörlein et al. (2005) used acoustic parameters obtained by spectral analysis of ultrasound echo signals to classify the carcasses based on intramuscular fat content non-destructively. Olsen et al. (2007) used this technique for online pig carcass classification. Live-animal ultrasound measurements can be used to predict retail product yield after slaughter. Williams et al. (1997) measured rump fat thickness and biceps femoris depth in live animals to predict retail yield and amount of trimmable external fat in beef. King (2004) used ultrasound to sort weanlings based on predicted meat quality at harvest with the aim of herd discrimination. Park et al. (1994) evaluated the ultrasonic spectral feature analysis for measuring beef sensory attributes noninvasively.

Nuclear magnetic resonance imaging (NMRI)

Certain nuclei (spin quantum number $i \neq 0$) have a magnetic moment and align along a strong static magnetic field. NMRI thus works on the principle of resonant magnetic energy absorption by nuclei placed in an alternating magnetic field. The amount of energy absorbed by the nuclei is directly proportional to the number of a particular nucleus in the sample such as the protons in water and oil. Ruan and Chen (2001) presented detailed theory of Nuclear Magnetic Resonance (NMR). This method can be used for noninvasive quality evaluation of many foods. NMRI properties of chemical components of meat can be used to evaluate a number of parameters related to meat quality, including: the fat content and distribution, water content, water holding capacity, collagen content, pH, and metabolites such as lactate, glycogen, phosphocreatine and ATP.

Mitchell (2006) and Bertram et al. (2007) used NMRI for studying postmortem metabolism to get insights of water mobility and water holding capacity mechanism. Bertram et al. (2002) also used ^{31}P-NMR spectroscopy to elucidate post mortem degradation of phosphorus metabolites (phosphocreatine mainly) by different stunning methods. Straadt et al. (2007) combined confocal laser scanning microscopy and low-field nuclear magnetic resonance relaxation to elucidate changes in microstructure and water distribution in fresh and cooked pork. Thus the induction and progress in post mortem changes monitored by NMR can be correlated to water holding capacity in meat.

Ballerini et al. (2002) analysed the isolated cross-sectional slices of the meat and measured the volumetric content of fat. Collewet et al. (2005) and Monziols et al. (2006) used NMRI for determination of the lean meat percentage of pig carcasses and recommended that NMRI could be used in place of full dissection for authorizing and monitoring classification equipment of pig carcasses.

Electronic nose

Indeed, the appeal of most flavors is more related to the odor arising from volatiles than to the reaction of the taste buds to dissolved substances. An "electronic or artificial nose" is an instrument, which comprises a sampling system, an array of chemical gas sensors with differing selectivity, and a computer with an appropriate pattern-classification algorithm, capable of qualitative and/or quantitative analysis of simple or complex gases, vapors, or odors. The entire genus of electronic noses includes those with conductive polymer, polymer composite, quartz crystal microbalance, surface acoustic wave, calorimetric, and other classes of sensors. The term "electronic nose" is used to indicate artificial olfaction, since many modern electronic noses are constructed with more than one class of sensors in them. E nose can replace some of existing methods of fresh meat quality evaluation based on expensive and relatively subjective taste panels and slow and invasive chemical tests. Limited number of investigations on use of electronic nose for meat are reported in literature and some of them are reviewed briefly below.

Descalzo et al. (2007) differentiated the antioxidant status of pasture or grain fed beef based on their odour profile using electronic nose. Vestergaard et al. 2006 demonstrated the potential of electronic nose based on ion mobility to detect boar taint of male pigs. O'Sullivan et al. (2003) showed that warmed over flavour in pork data using e nose was correlated well with sensory data. Ground meats are used extensively as an ingredient in various food products. The process of grinding meat introduces air (thus oxygen) into close proximity of oxidisable lipids which causes rancidity in meat and meat products. Cooked meat products prepared from even slightly rancid meat tastes cardboardy and painty and is considered unacceptable by consumers. Braggins et al. (1999) showed capability of electronic nose in conjunction with panelists to quickly assess the onset of rancidity in frozen ground beef. Odors / volatile profiles vary for meats obtained from animals of different origins and odours also depend on diet as well. Panigrahi et al. (2006) obtained 100% accuracy of classification of beef based on volatile compounds released due to increased microbial load with commercially available electronic nose integrated with neural networks.

Conclusion

Non-destructive quality evaluation methods which have shown great potential for meat are colour and computer image analysis, Visual NIR spectroscopy, NMRI, electronic nose, ultrasound, x-ray imaging and biosensors. Colour and computer image analysis correlate well with wholesomeness of meat, marbling of fat, tenderness, diseases and disorders and effects of treatments and storage period. The accuracy was reported to be in the range of 72% to 95%. Visual NIR spectroscopy is another versatile technology to cover broad spectrum of applications ranging from biochemical composition, texture profile, wholesomeness of meat, intramuscular fat, tenderness, diseases and disorders and effects of treatments and storage period. The accuracy of the method was more than 90% for many applications. The colour, machine vision and image analysis and NIR spectroscopy are in nascent stage in India with few research institutes working but they hold great potential for future. Ultrasonics and x-ray could be used for predicting body composition of live animals and for online inspection systems. NMRI can be used to find water mobility and distribution, water holding capacity, intramuscular fat, muscle content of carcass and postmortem changes in meat. Biosensors show great promise in rapid detection of very low levels of pathogens in meat products. Electronic nose is becoming popular for assessment of freshness, microbial spoilage, antioxidant status of meat and it can supplement other methods for quality evaluation of meat and meat products.

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