Non invasive methods for egg quality evaluation

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During the last century, egg production, transport and handling became a specialized industry. Egg quality was for a long time based on visual inspection. Today, the total number of the handled eggs and the rate of grading (up to 180 000 eggs/hour) is such that this visual inspection becomes impossible. This leads to a search for new non invasive devices to measure egg quality parameters.
In the last decade, at least three types of quality sensing devices became commercially available. A first type is based on mechanical techniques that measures eggshell properties as there are the presence of cracks and the eggshell strength. A second type of sensors is based on spectroscopic principles for interior egg quality. Originally, the spectroscopic information was based on one or a limited number of wavelengths using filter systems (e.g. to detect blood or other inclusions). Later, with sophisticated spectroscopic equipment, the hyper spectral information carried by transmitting light could be linked with albumen properties like pH, Haugh Units and viscosity.
Finally a third type of sensor system uses computer vision techniques to get information about the outside of the egg. (e.g. eggshell colour and the detection of dirty shells). It also allows the rapid detection of open cracks that are a problem for hygienic conditions and cleanliness of egg grading equipment.
Ongoing research also focuses on new sensors based on ultrasonic, magnetic resonance and electronic nose techniques. Moreover, by combining two different measurement techniques other characteristics become assessable (e.g. eggshell conductance).
These sensor devices became available in egg quality research groups, relationships between a specific quality parameter and the general condition of the measured egg and the sampled layer flock have been established. Estimations about both the general egg quality and the health of the layer flock can be made and used for flock management in order to correct problems before they cause large economic losses or hygienic problems. This will increase the general egg quality and reduce the risks for the consumers when eating eggs and egg products.

Keywords: Non-invasive measurements, egg quality, albumen quality, shell quality

Introduction

Eggs and processed egg products have always been an important part of the human diet worldwide due to the easy way to produce them and their high nutritive value. However, since infections of the egg with bacteria like Salmonellae are common, eggs are also an important vector for food poisoning causing human intoxications (EU, 2003). Research has shown that the infection causing eggs often lack in their general egg quality. Therefore, to maintain food safety the search for the highest possible egg quality is an important issue for everyone who is in charge in the production of eggs and egg products.

Besides of the safety, eggs have to compete with an increasing number of other products in the food industry. Here, eggs have to overcome some disadvantages as there are the high natural variability of the different quality aspects and the presence of a fragile eggshell, requiring a sophisticated gentle way of handling these eggs in automated grading systems. Since consumer demands for egg quality are continuously increasing, the egg quality graders needs continuous improvement.

Egg quality consists of different quality aspects, each of them can be related to interior egg quality or external egg quality. Most of the exterior egg quality aspects are related to the egg shell, as there are the shell integrity, colour, thickness, porosity and the shell strength. Other external quality aspects are the presence of dirt on the shell and a cuticle. Except for the shell colour, these external egg quality aspects are related the main function of the eggshell: the protection of the inside of the egg against physical damage and bacterial invasions.

Internal egg quality relates in general to the quality of the albumen. Due to biochemical reactions, governed by complex internal and external factors as temperature and relative humidity and the presence of bacteria, this albumen quality decreases with storage time. The albumen evolutes from a consistent, highly viscous product to a watery substance during several weeks. Therefore, albumen quality is often taken as a yardstick to evaluate albumen (and egg) freshness. Historically, albumen quality is estimated by Haugh Units (Haugh, 1937), which are a measurement of the albumen height after breakage empirically corrected for the egg mass. Although it is easy, this technique has some important disadvantages. Besides the freshness of the albumen, albumen can include dissolved blood, bloodspots and meat spots (i.e. inclusions other than blood).

The rate at which eggs are graded today (up to 180.000 eggs/hour) using egg grading equipment, is of that order that eggs cannot be controlled individually by a trained human eye. Therefore, the egg grading equipment is equipped with specially developed sensor devices to estimate one or more quality aspects of the graded eggs. It is clear that the installed devices have to be non destructive and fast. If possible, to prevent cross contamination of infected eggs, they have to be non contact. During their development these novel devices were compared to the classic test for the quality aspects that are usually destructive and time consuming.

In this text, the different techniques that are available for non invasive evaluation of product quality are discussed. In general, three different types can be distinguished: mechanical measurements, spectroscopic measurements and vision techniques. There is also research towards other measurement techniques to evaluate particular aspects of egg quality.

Mechanical techniques

A lot of mechanical techniques have been used to evaluate the physical quality like the strength and the integrity of the shell. A whole set of mostly destructive and time consuming different protocols to evaluate the physical quality is reviewed by Hamilton (1982). These techniques are often used as a reference technique to evaluate the development of fast and non invasive techniques.

For the non invasive evaluation of eggshell strength and integrity, a mechanical technique is the basis for a device to detect hair cracks in commercial egg grading machines. In these devices, the local integrity of an eggshell is checked by measuring the number of rebounds of a small impactor on the eggshell.

Several elastic rebounds of this impactor indicate a locally intact eggshell. Close to a crack in the eggshell, the elasticity of the eggshell impairs the rebounds of the impactor which is heavily damped. This is reflected in a serious reduction of the number of rebounds of the impactor. Applying these measurements on several places of the egg, cracks all over the egg can be detected. In one application (Moayeri, 1996), the impactor is a small ball moving electromagnetic probe. In another commercially available application, the egg itself acts as the impactor and the rebounds are counted by a piezoelectric element (Bliss, 1973). With these techniques, the crack detection rate varies from 70 to 85%. Therefore, 24 to 36 local measurements have to be done on each egg.

Coucke (1998) and later De Ketelaere *et al.* (2000) proposed to analyse the dynamic response of the egg itself after an excitation. After excitation, the egg will exhibit to a complex damped harmonic vibration. For an unbroken eggshell, this vibration is identical wherever measured on the equator of the eggshell. Hence, by comparing the frequency spectrum measured at different places on the equator of the vibrating egg, it is possible to judge the integrity of the eggshell. Broken shells will show a different response on different locations of the equator. Using this fast technique, one measurement takes about 7 ms, only 4 measurements are needed to detect up to 90% of the cracked egg. Using multiple regression and discriminant analysis, Cho *et al.* (2000) increased the detection rate to 94%. Later on, Jindal and Sritham (2003) were able to detect almost 99% of the cracked eggs. In their research, neural networks were used to compare the recorded spectra. However, the latter two report and amount of false rejects of 4% and 10% respectively, compared to 1% using the technique developed by Coucke (1998). Recently, research of Wang and Jiang (2005) has shown the possibility to detect cracked eggshells by comparing the vibrational behaviour at the blunt end and at the equator after an excitation at the equator.

Further research reported by Coucke *et al* (1999) and De Ketelaere (2002) made it possible to calculate the dynamic stiffness from the measured frequency spectrum for intact eggshells. This dynamic stiffness was correlated with other eggshell strength parameters as there are the static stiffness and the eggshell thickness. Bain *et al.* (2006) reported research in which it is shown that the probability for an egg to crack during handling and transport can be predicted using the here discussed Acoustic Technique for measuring the dynamic stiffness. Messens *et al.* (2006) found eggs with a reduced dynamic stiffness to be more easily penetrated by micro-organisms as S. enteritidis.

Spectroscopic techniques

In general, light is composed of a collection of electromagnetic waves of a broad spectrum of wavelengths, the so called visible range (VIS) with wavelengths between 300 and 750nm and the Near Infra Red range (NIR) between 700 and 2500 nm. When passing through material, this spectrum is changed due to physical and chemical interactions. After comparing the changed spectrum with the original spectrum, optical information of the object through which the light passed is obtained and this information can be linked with chemical and physical quality aspects of this object. Several researchers have found reliable ways to link this optical information with quality aspect of consumption eggs. The advantage of optical measurements is that their nature is non destructive and fast. Moreover, they can be realised without any contact with the egg itself and hence the risk for cross contamination does not exist.

Work reported by Bamelis (2003) on white shelled eggs shows an important inter egg variation in optical transmission spectra, using visible light. This time independent variability could be declared by the size of the egg and the thickness of the eggshell. Besides these inter egg variability, a variation during the storage of eggs was found. From these optical spectra, the transmission ratio of two wavelengths 674 and 663nm was calculated and this ratio has been shown to evolve logarithmically towards a constant value, but the time to reach this constant differs from egg to egg. The latter might be related with the speed of the aging processes going on in the measured egg. A time dependent evolution of the optical spectra, but in this case in the NIR range, was also reported by Norris (1996).

Kemps *et al.* (2004) investigated the possibility to estimate albumen quality parameters pH and Haugh Units (HU) from the optically measured VIS-NIR transmission spectra. A correlation of 0.82 between

predicted and measured parameters was reported. Schmilovitch *et al.* (2002) could predict pH from NIR transmission spectra measured trough whole eggs. Repeated by Kemps *et al.* (2004), the same conclusions were found for pH and HU. Here 94% of the variance in HU was declared by the PLS models. However, in the same research it was shown that only a 66% of the variation of pH could be explained by the variation on HU of eggs during their storage. It was concluded that the underlying mechanisms for the variable pH and HU are the same, but due to additional error (e.g. measurement error) they might be not the best indicator for the freshness of eggs. A better reference should be the viscosity of the albumen, but standard protocols to measure this are not yet available.

During the lights travel through the egg, the optical spectrum can be influenced by optical active pigments. The detection of two important pigments (haemoglobin and protoporphyrin) are the basis for two devices that are commercially available today. Blood and the colour of eggshell are measured by the detection of their most important pigments.

A technique to detect blood in a non invasive way was first proposed by Brant *et al.* (1953). He selected the absorption peaks of haemoglobin at 577nm to predict the presence of blood inside the egg. To correct this value for the inter egg variable factors such as shell thickness and egg size, the presence of blood was detected by a ratio between the transmittance at two wavelengths, i.e. the bloodvalue (577nm/610nm). Later on, Gielen *et al.*(1979) showed the range between 585 and 610nm being useful as a reference value to calculate the bloodvalue. A problem in the detection of blood might be the presence of protoporphyrin in the shell of brown eggs. This pigment resembles very well haemoglobin and its optical absorption peaks are very close to those of haemoglobin. Hence, when present in the eggshell, protoporphyrin disturbs the detection of blood in that way that even the detection of blood inside the egg can become impossible.

An advantage of the optical activity of protoporphyrin on the other hand is that by its optical detection, the colour of eggshells can be measured (Lang and Wells, 1987). Besides protoporphyrin, biliverdin is an important eggshell pigment for the eggshell colour (Kennedy and Wevers, 1973). Using the reflected light by an eggshell, Wei and Bitgood (1989) were able to develop a device to measure the eggshell colour.

Vision techniques

For egg grading purposes, computer vision techniques are used in three main applications. First, effort goes to develop a computer vision system to detect open cracks and hair cracks in eggs. The first authors reporting this application were Elster and Goodrum (1991). Based on their work, later Patel *et al.* (1994) could increase the detection rate towards 90% using a decision algorithm based on neural network development. Instead of the neural network analysis, Han and Feng (1994) used a two dimensional Fast Fourier Transformation to extract relevant information from the images, but their detection rate was not more than 88%.

Bloodspot detection was also done using computer vision. Using an colour image analysis combined with a neural network detection technique, 92.8% of the bloodspots in eggs could be detected (Patel *et al.*, 1998).

Dirt stains can be detected in different ways, as reported by Patel *et al.* (1994), Garcia-Alegre *et al.* (1997-2000) and Ribeiro *et al.* (2000). Recently, new research has shown the possibility to differentiate for the different types of dirt that can be found on the egg (faeces, uric acid, yolk and blood). This was done with a high accuracy and a rather low computing time, making on-line implementation possible (Mertens *et al*, 2005)

Other research

Recently, Capozzi *et al.* (1999) and Schwägele *et al.* (2003) showed low resolution Nuclear Magnetic Resonance (NMR) as a possible non-destructive method to determine the quality of intact eggs. Changes

in the transversal relaxation times during storage were reported due to the increasing liquefaction of the albumen.

The freshness of eggs can be determined by an electronic nose based system, using an array of four commercial tin-oxide odour sensors. Using this setup, Dutta *et al.* (2003) were able to classify eggs into three different freshness stages with up to 95% accuracy.

Bamelis *et al.* (2006) used the dynamic stiffness measured by Acoustic Resonance Analysis combined with the optical transmittance at 611nm to estimate the eggshell conductance for water vapour, what is determined by the porosity and the thickness of the eggshell. A correlation of 0.69 was found, indicating the possibility to divide eggs in high- and low- conducting eggshells. This may be useful for incubation practice or to state the risk that eggshells can be easily penetrated by bacteria.

Use of these techniques in applied egg research

Several of the discussed techniques can be used to measure quality parameters of incubation eggs. The most useful information in this sector is retrieved from the inside of the egg, where the embryo is developing. It has been shown that the Acoustic Resonance Analysis is able to select eggs in which an embryo is developing after 96 hours of incubation. By calculating the bloodvalue retrieved from optical transmission spectra, embryonic presence is even detected after about 72 hours of incubation (Bamelis *et al.*, 2004).

Furthermore, the determination of the dynamical stiffness by the Acoustic Resonance Analysis is used by other authors to state the effect of heat stress on a layer flock (Lin *et al.*, 2004) and to compare the risk for shell breakage in different production chains (Mertens *et al.*, 2006).

For selection of new breeder flocks both for layers and broilers, it is of importance to include information about eggshell quality in the selection program. Since the dynamical stiffness shows a high heritability (Dunn *et al.*, 2006) and seems to be a good estimator for the risk of the shell to crack during handling and transport (Bain *et al.*, 2006), the fast and non invasive measurement of it might be a useful tool in the breeding.

General conclusion

It has been shown that, a long lists exists of techniques that can be used to grade eggs are available. Some of them are used already on commercial grading machines. The possibilities of other techniques have to be explored more in detail before they become of real commercial value. The price to implement other techniques is too high or computer time needed for the measurements is too long and hence more development is needed to solve these problems.

An interesting idea for the scientists involved in the development of these techniques is to use combinations of different non invasive techniques to define the risk that an egg can be dangerous for the consumer's health. Before this will be possible, we have to be able to make more links between the inner content of the egg and the bacterial defence mechanisms present in the egg. In our opinion, the VIS/NIR spectroscopic technique might be most useful here.

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