Applications of near-infrared imaging for monitoring agricultural food and feed products

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1. Introduction

The use of near-infrared spectroscopy (NIRS) for the analysis of agro-food products began in the 1970s with Karl Norris' pioneering work demonstrating the high potential of this approach (Williams and Norris, 2001; Bertrand and Dufour, 2001). NIRS techniques are now regarded as attractive and promising analytical tools for use in research, control and industrial laboratories. Analysts increasingly consider them as the way ahead for food and feed analysis. This trend stems from the extensive use of computers as well as developments in instrumentation and in appropriate chemometric procedures. New applications of spectroscopic techniques in chemical, pharmaceutical, life science, agro-food and environmental analysis are emerging with great frequency now. The evolution of instrumentation in infrared spectroscopy has been particularly rapid in process analytical chemistry, a crucial aspect of the pharmaceutical, chemical and agro-food industries. Analysis is moving closer to the sampling point or the field by means of fibre optics, allowing real-time analysis and continuous control of processes or embedded instruments. There is also a trend towards developing analytical chemistry systems combining the instrument, the interface between the instrument and the sample (i.e., sample presentation device), and the software integrating data acquisition, data archiving and chemometrics for specific applications. A more recent development is the use of the spectroscopic imaging instruments for the control and monitoring of agricultural food and feed products. For analysts and researchers, this is something of a revolution, with hundreds or thousands of spectra being collected for each sample, process or experience, instead of one spectrum using classical NIRS instruments. The challenge is to extract and exploit the relevant information contained in the huge amount of data now available (Baeten and Dardenne, 2002).

Earlier in the book, the applications of NIRS imaging for material science as well as for the biological and biomedical sciences were reviewed and discussed. This chapter looks at how this technique can meet challenges in agricultural food and feed product analysis. A wide range of applications for agricultural purposes has been developed, including satellite and aircraft remote-sensing, macroscopic imaging for food quality control, microscopic imaging for feed control, and the study of plant physiology (Budevska, 2002). Taylor and McClure (1989) demonstrated the great potential of NIRS imaging for measuring the distribution of chemical components (Taylor and McClure, 1989). They worked with a CCD video camera with an effective sensitivity of 400–1100 nm and narrow band interference filters, and used the combination of spectral image data recorded at the different wavelengths to measure the distribution of chlorophyll and moisture in plant material (tobacco). More recently, using an AOTF-based NIR multispectral imaging instrument, Tran and Grishko (2004) demonstrated the potential of this technique for determining the water content of olive leaves.

Two points need to be made here about the following discussion. First, most of the studies featured in this chapter concern the use system active simultaneously in part of the visible (400–700 nm) and near-infrared (700–2500 nm) ranges in relation to various problems. Second, the focus is on a limited number of papers that provide a broad overview of the potential applications of this technique for the agricultural food and feed sectors. The chapter reviews the application of the NIRS imaging for: (i) the remote control and monitoring of agriculture; (ii) the analysis of food products as part of food chain quality and safety control; and (iii) the control of compound feeds at the ingredient particles level, in compliance with animal feedstuffs regulations. All the NIR images shown in the chapter were collected at Walloon Agricultural Research Centre with a MatrixNIR^{TM} instrument (Spectral Dimensions Inc., Olney, USA). This instrument includes an InGaAs array detector (240 320 pixels) active in the 900-1700 nm range.

2. Use of near-infrared imaging for remote control and monitoring in agriculture

2.1 The problematic

Traditionally, remote-sensing images used to observe the reflected light from the sun by the Earth have been divided into two main categories. The first category includes the satellite-based images that cover large areas, with relatively fixed time intervals and a low spatial resolution. The second category includes airborne-based images that usually cover small areas, with flexible flight schedules and high spatial resolutions (Yao *et al.*, 2001). The history of remote-sensing of the Earth began with the Landsat 1 satellite, a multispectral spectroscopic instrument, launched by NASA in 1972 (Curran, 1989). Other similar and well-known instruments were the SPOT (Satellite Pour l'Observation de la Terre) and AVHRR (Advanced Very High Resolution Radiometer) satellites. Multispectral techniques involve the use of a small number of spectral bands (generally less than 10) from the visible and near-infrared ranges. In multispectral instruments the optimal bands are for a specific analysis or monitoring. Multispectral systems are less expensive, produce smaller datasets and have a greater signal-to-noise ratio (S/N). However, they produce data only from a limited number of broad bands.

The first airborne based system, the Airborne Imaging System (AIS), became operational in 1983. AVIRIS (Airborne Visible and Infrared Imaging Spectrometer), based on the AIS concept and covering the electromagnetic spectrum from 400 nm to 2500 nm with narrow bands, became operational in 1989 (Vane and Goetz, 1993). Another example of a hyperspectral airborne sensor is CASI (Compact Airborne Spectrographic Imager). Tools developed for geological science have greatly influenced the increasing interest in hyperspectral information for remote sensing and the rapid development of imaging spectrometry to meet agricultural challenges. Hyperspectral technologies produce contiguous spectra with tens or hundreds of bands with a narrow bandwidth (one to several nanometers) in the same spectral range of the multispectral instruments. The resolution of a hyperspectral instrument is considered to be enough for the identification of most of biological materials (Jacobsen, 2001).

Satellite and airborne remote-sensing data are subject to large distortions that could substantially reduce their usefulness. There are three main distortion factors that could interfere with the collection of spectroscopic imaging data from space or airborne instruments for agricultural applications (Vane and Goetz, 1993; Jacobsen, 2001): (i) the system distortions, including those resulting from sensor calibration, scanner construction and engine (e.g., aircraft) instability; (ii) the sun, an important factor to take into account in remote sensing using spectroscopic imaging instruments; this passive optical system and the atmosphere through which the energy passes, both from the sun to the Earth's surface and back to the instrument, interferes with the data collected; atmospheric distortions include the effect of scattered dry air molecules (haze) and absorption by air molecules; and (iii) the geometric distortions related to an unstable platform, a low acquisition altitude and a large field of view. Sophisticated algorithms have been developed to reduce the impact of these distortions on the collected image data (See chapter XXX).

In the 1990s it was recognised that the reflectance data obtained with remote sensing were highly valuable for modelling biophysical parameters. The spectral reflectance data extracted from hyperspectral instruments, however, are more sensitive than those collected with multispectral instruments for detecting different parameters and have extended the field of application of spectroscopic remote-sensing technologies. The scope of the application of remote sensing is broad, and image data are essential inputs in environmental and ecological research (examples of applications include observation of ecosystems, fluvial geomorphic features, plant species mapping, woody debris distribution, vegetation water content, natural resource management, forest mapping, detection of pollution, and fisheries oceanography) (Santos, 2000; Curran, 2001; Kerr and Ostrovsky, 2003). Another important area for the application of remote-sensing technologies is agriculture. The following section outlines the use of hyperspectral data for the *determination of vegetation indices*, for *precision agriculture* and for the *characterisation of grassland canopy*.

2.2 Determination of vegetation indices

In order to determine agricultural crop characteristics, the vegetation indices (VIs) are calculated using spectroscopic remote-sensing imaging data (Wessman *et al*., 1997; Clevers, 1999; Clevers and Jongschaap, 2001). To minimise the undesirable disturbances of differences in soil background and atmospheric conditions, they are combinations of the reflectance in different wavelength bands. The VIs used to quantify crop variables include the leaf area index (LAI), wet biomass (WBM), plant height (PLNTHT) and grain yield (YLD) indices, all of which are affected by climate, soils, cultivars, cultural practices, management and technological inputs, and are regional in nature (Thenkabail *et al*., 2000). LAI is known to be one of the first plant responses to stress (Barlett *et al*., 1988). It is directly related to the exchange of energy, CO_2 and mass from plant canopies (Fassnacht *et al*., 1997), and is sensitive to leaf cell enlargement due to water deficit (Shibayama *et al*., 1993). LAI is used to compute evapotranspiration (Clevers *et al*., 1994) and to compare terrestrial ecosytems worldwide (Running, 1989). The WBM and PLNTH indices are excellent indicators of crop growth conditions and potential yield. WBM is also a good indicator of leaf and crop moisture. All these VIs involve two wavelength bands. The hyperspectral imaging data may be crucial for providing additional information and improving the traditional VIs.

Another important index is the red-edge index derived from hyperspectral data, which is increasingly being used to determine crop characteristics (Clevers, 1999, Clevers and Jongschaap, 2001). The position of the red-edge is defined as the inflexion point (or maximum slope) of the red-NIR slope. Its determination requires a large number of spectral measurements in narrow spectral bands in the 680–780 nm region. The use of the position and shift of the red-edge index combined with other parameters has been successfully used to determine crop nitrogen status or nitrogen deficiency and to monitor the growth of some crops, such as potatoes and sugar beet (Broge et al., 1997. Cited in Jacobsen, 2001).

2.3 Precision agriculture

Spectroscopic imaging data acquired by aircraft or satellite could also play an important role in the development of precision agriculture. These technologies have the potential to detect crop stress and diagnose its cause before a farmer is able to spot the problem with the naked eye. The aim of remote sensing in precision agriculture is to provide farmers with detailed information that can be used to tailor the application of water, pesticides or fertilizers to crop needs. Other aims include verifying the effectiveness of variable-rate fertilizer applications, verifying the effectiveness of fungicide applications, quantifying loss due to accidental spray drift damage, and monitoring physical damage due to insects, flooding, wind or hail (Seelan et al., 2003). Spectroscopic remote-sensing imaging technologies used with geographical information systems (GIS) and global positioning systems (GPS) may provide tools that will enable farmers to maximise the economic and environmental benefits of precision agriculture (Seelan *et al.,* 2003). By carefully identifying in-field variability, farmers can find a balance between production maximization and environmental stress reduction. It is important to mention that while spatial resolution is valuable in monitoring crop appearance, it is the spectral signature that reveals the most information about plant stress and health. Also, the hyperspectral technologies produce more data than multispectral technologies, allowing a farmer to determine whether the stress observed in a field is caused by water depletion, insect infestation, poor fertilization or weed invasion (Yao *et al*., 2001).

One of the most useful applications of spectroscopic remote-sensing imaging is the possibility of the early detection of infestation in crops, enabling eradication using a local treatment. Late detection results not only in financial loss, but also requires aerial spraying and the use of chemicals that are harmful to the environment. Agricultural remote-sensing approaches using spectroscopic imaging technology have been proposed, for instance, for characterising and determining the severity of fungal diseases in wheat (Hamid and Larsolle, 2003). The aim of this study was to discriminate between healthy and diseased areas in a spring wheat crop suffering from fungal infestation, and to determine the plant-cover damage level in the affected areas. The main advantage of this approach is that it is suitable for real-time use. The hyperspectral crop reflectance data used consisted of 164 bands in the 360–900 nm region. Another important area is the detection of invasive weeds – also called noxious weeds – using the spectroscopic imaging systems. This approach could offer the possibility of generating timely and accurate weed maps (Lamb and Brown, 2001).

2.4 Characterisation of grassland canopy

The spectroscopic imaging data provided by airborne hyperspectral imagers could also be used to characterise grassland canopy (Buffet and Oger, 2003a and 2003b). Grasslands are an important component of agricultural landscape in some European countries, such as Belgium, and under current regulations it is mandatory to monitor them. At regional level, grassland monitoring is closely linked to the knowledge of regional management systems, the inventory of forage production and the quality and control of agri-environmental measures. The work conducted by Buffet and Oger (2003b) sought to demonstrate that hyperspectral remote-sensing imaging helps crop management by providing a continuous spatial and temporal assessment of the parameters characterising the canopy structure of each grassland area, as well as its biochemical and biophysical properties. This study was based on spectral remote-sensing observations and field observations of representative meadows in Lorraine in southeast Belgium. This region is characterised by important grassland areas under a wide variety of management systems. The remote-sensing data were collected in September 2002 from two spectroradiometric imaging systems mounted on a Dormier 228 aircraft. Hyperspectral data were acquired using a CASI sensor (Compact Airborne Spectrographic Imagers) working in the 400–950 nm region and a SASI sensor (Shortwave Airborne Spectrographic Imager) working in the 850–2500 nm region, with a ground resolution of 2.5 x 2.5 m and 2 x 2 m, respectively. The spectral resolution of the CASI and SASI sensors was 6 nm and 10 nm, respectively. Figure 1 presents the spectral features observed for the grasslands not harvested, grasslands just harvested, and bare soil. The study showed that relationships exist between physico-chemical parameters and hyperspectral data, enabling the quality of grassland canopy to be assessed and regional inventories of grass production potential to be drawn up. The study also demonstrated the possibility of discriminating between different types of meadows (e.g., pasture and mowed meadows) and the potential of combining information from two sensors operating in different regions of the electromagnetic spectrum. The potential of spectroscopic imaging for mapping grass quality in Africa's savanna rangelands has been also investigated (Mutanga and Skidmore, 2004).

3. Near-infrared imaging for food analysis

3.1 The problematic

The search for new methodologies to improve the overall quality and safety of products in the food chain is ongoing. Rapid and non-invasive methods that can be easily implemented to assess hazardous conditions in food production are required. Vibrational spectroscopy is one such method; it has been used successfully to evaluate the quality and safety of agro-food products. Its suitability for qualitative and quantitative analysis with little or no sample preparation, and its speed and high throughput, make it very attractive for the industrial sector. Traditional NIRS analyses in which one spectrum is obtained for each sample has the disadvantage of the results coming from an analysis (i.e. spectrum) of one small area or of several specimens of the sample. In contrast, the spectroscopic imaging method allows one to take account of the spatial variability of the sample materials analysed (Kim *et al*., 2001;

Budevska, 2002). The following section outlines the application of NIR imaging for analysing fruits, cereals and meat products.

3.2 Analysis of fruits

The main quality attributes of fruits are appearance (colour, size, shape, lack of defects), texture and flavour (ripeness). Consumer satisfaction, however, relates mainly to texture and flavour. The technology for sorting fruits according to appearance exists, but the analytical challenge of developing methods to determine quality parameters, in a non-destructive way, has still to be met. It is necessary to develop a powerful tool to identify and detect spectral and spatial anomalies due to defects and/or contamination (Martinsen *et al*., 1999; Lu, 2003; Kim *et al*., 2002).

NIRS imaging has been proposed as a means of assessing the external and internal quality of apples (Lu and Chen, 1998). Its potential has been demonstrated, for instance, in detecting external contamination in apples. Kim *et al*. (2001) used an imaging system working in the 430–930 nm region, with a spatial resolution of 1 mm, to detect fungal contamination in apples. This technology has since been applied to detect faecal contamination on the surface of fruit using only two NIR wavelengths (Kim *et al*., 2002; Mehl *et al*., 2004), and to detect soil contamination (Mehl *et al.,* 2004). These works showed that detecting faecal contamination using only information from the NIR region is less sensitive to variations in apple coloration. The detection is limited by the thickness of the faecal spot.

NIR imaging is also promising for detecting defects on the surfaces of apple varieties. Work has been also conducted on developing spectroscopic imaging systems to detect bruise defects and open skin cuts (Kim *et al*., 2001; Lu, 2003; Mehl *et al.,* 2004). The detection of bruises on apples is crucial for the industry, and retailers in particular, as this defect reduces the quality of the fruit considerably, leading to financial losses. Lu (2003) developed a NIR hyperspectral imaging system covering the 900–1700 nm spectral region to detect bruises. He was able to detect bruises on apples, but he also showed that the spectral information included in the 1000–1340 nm region was not appropriate. Mehl *et al.* (2004) using an imaging system in the 430–900 nm range, showed the potential of the method for detecting bruises in various cultivars. They concluded that the NIR bands were not subject to colour changes from the various apple cultivars studied and that there was no single waveband image that could be used easily to differentiate normal apples from bruised apples. They used the asymmetric second difference method to extract the relevant information from the spectra. NIRS imaging has also been investigated for analysing internal quality parameters. Studies have shown that the firmness and soluble solid content of apples can be predicted using selected near-infrared wavelengths (880, 905 and 940 nm) (Lu, 2003; Lu, 2004). A method to measure starch distribution and the starch index of apples during maturation has been developed using NIRS imaging technology (Peirs *et al*., 2003). The use of this technology to detect bitterpit in apples has been also proposed (Bellon-Maurel *et al*., 1999).

NIRS imaging data has been used for assessing the internal characteristics of other fruits. Martinsen and Schaare (1998) were able to calibrate an imaging instrument for predicting the concentration of soluble solids in ripening kiwifruit using the near-infrared reflectance spectra in the 650–1100 nm range. The calibration models had a standard error of 1.2 °Brix over a range of 4.7–14.1 °Brix and were used to show the spatial distribution of soluble solids in cut sections of fruit. Sugiyama (1999) and Tsuta *et al*. (2002) used NIRS imaging for evaluating the quality of melons, and studied the distribution of sugar in the fruit. Other applications include distinguishing between dark and berries in green grapes (Bellon-Maurel *et al*., 1999) and measuring the ripeness of tomatoes (Polder *et al*., 2000). Figure 2 shows the PC 3 image obtained from the NIR spectroscopy image of raspberries with different grades of ripeness. Figure 3 present the NIR images at 1340 nm (A) and 1410 nm (B) of white currants. The fine external and internal structures of the berries can be observed

3.3 Single-kernel analysis of cereals

Among the most important ingredients in diets throughout the world are cereals such as wheat, rice and maize. Significant efforts need to be made to ensure there is no contamination of cereals during production and storage. Such contamination includes adulteration by other cereal species or seeds from other crops, decayed and damaged grains (e.g., mouldy grains), animal faeces (e.g., from birds and rodents), seed contaminated with mycotoxins, and insect infestations. Cereal contamination results in a loss in the quality, which in turn leads to financial losses for both the producers and retailers if it is not detected at an early stage. Contamination rarely occurs at significant levels; methods that are able to detect defects at the grain level are needed. The target of analytical tools should be to detect one contaminated grain per kilogram. An important factor in developing methods for performing single-kernel analysis is their potential in the breed sector. It has been shown that genetic improvements can be significant when breeding selection is performed on a single-kernel basis (Silvela *et al*., 1989).

As a first step, classical NIRS instruments were adapted for single-seed analysis in order to meet the specific analytical requirements in detecting defect and contamination (Chambers and Ridgway, 1996; Ridgway *et al*., 1999; Wang *et al.,* 2002). Subsequently, work was carried out to demonstrate the potential of the NIRS imaging technique, which has the advantage of not being influenced by the heterogeneous morphology of products such as maize, or by the distribution inside the grain of the parameter to be determined, because the entire kernel is analysed using imaging methodology.

Ridgway and Chambers (1998) demonstrated the potential of NIRS imaging for detecting insects inside wheat kernels. They used a Hamamatsu NIR vidicon camera (C2400 series) and collected the reflectance image at wavelengths 1202 nm and 1300 nm using appropriate filters. These wavelengths were selected on the basis of a previous study in which classical NIRS instruments were used (Chambers and Ridgway, 1996). They used the subtracted image (1202 nm – 1300 nm) to detect grains internally infested with grain weevil larvae, based on the detection of changes in kernel composition. Later, they demonstrated the potential of NIRS imaging not only for detecting weevil larvae in kernels but also for detecting grains infested by insect pests (adult beetles and larvae in wheat) and ergot (parasitic fungi which form mycotoxins poisonous to both humans and animals) in wheat (Ridgway *et al*., 2001). This methodology can be used to detect infested kernels in other plant species. Figure 4 presents the analysis of single kernels by NIR imaging spectroscopy to detect insect infested grains. Figure 4A presents the image at 1400 nm of three infested wheat kernels. Figure 4B shows the fifth PC image of the NIR image of intact (1) and infested (2 & 3) coffee beans.

Hurburgh and collaborators (Cogdill *et al.,* 2002; Stevermer *et al*., 2003; Cogdill *et al.,* 2004) studied the potential of hyperspectral NIR techniques for analysing single-kernel maize. They developed an automated kernel analysis and sorting system to single out maize kernels and place them in the field of view of a near-infrared spectrometer for analysis and classification. The imaging system used included a NIR camera active in the 700–1100 nm region and a liquid crystal tuneable filter to select individual wavelengths. They showed that it was possible to predict moisture and oil concentration in a single kernel with a standard error of cross-validation of 1.2% and 1.4%, respectively. This method was also used to study the distribution of moisture and oil in individual kernels. One of their conclusions was that a major limitation of this technique is the poor quality of single-kernel reference chemistry. similarly, a project aiming to use a NIR imaging system active in the 900-1700 nm region has been initiated at CRA-W to study the distribution of component in wheat kernel. Figure 5 shows the results of wheat grains analysis by NIR imaging. The image displays the NIR image at 1140 nm, spectra of the germ (dotted line) and albumen (continuous line), as well as the sixth PC image bringing to the fore the germ of each kernel.

3.4 Analysis of meat

Spectrometric imaging has been also proposed for analysing meat products, particularly poultry carcasses. Currently, meat control (i.e., the detection of faecal and ingesta contamination) is performed by visual observation. The interest in using spectroscopic imaging is because it will be able to provide physical and chemical information of the products analysed. This information could include physical and geometric observations of size, orientation, shape, colour and texture, as well as chemical and molecular information (e.g., water, fat and protein content). Several papers have proposed using a VIS/NIR imaging system operating in the 400–900 nm region to detect faeces and ingesta contamination in poultry carcasses (Park *et al.,* 2002; Lawrence *et al*., 2003). They have shown the usefulness of this method and concluded that the impact of using different feed ingredients in the formulation of compound feed on the VIS/NIR spectra should be investigated. The selection of the most interesting wavelengths has been also investigated (Windham *et al.,* 2002). A dual-wavelength spectral imaging system has been proposed for classifying poultry carcasses (Park *et al*., 2002; Chao *et al*., 2002). Chao *et al*. (2002) proposed hyperspectral and multispectral systems for detecting chicken skin tumours. They used a spectroscopic imaging system active in the 420–850 nm region and a fuzzy inference system to distinguish tumours from normal the skin tissue. The technique has also been used to characterise heart disease in chickens (Chao *et al*., 2001).

4. Near-infrared imaging for feed analysis

4.1 The problematic

With the emergence of the BSE crisis, firstly in Europe and later in other parts of the world, authorities have taken a lot of legal decisions in order to assure the human safety. One of them is the partial or total ban of the use of animal protein in compound feed. Originally, classical microscopy was the only method available for the fight against fraud or accidental contaminations of feedingstuffs with meat and bone meal (MBM) (Gizzi et al., 2003). Near-infrared spectroscopy (NIRS) has been also proposed to solve this analytical challenge (Garrido et al., 1998; Murray et al; 2001). With this technique, a single spectrum is obtained from the analysis of one sample (e.g. feed ingredient or compound feed). Recent developments have lead to hyphenated instrument coupling a near infrared spectrometer and a microscope (NIRM instrument). With this instrument, spectra of up to hundreds or thousands of particles can be obtained from the analysis of one feed ingredient or one compound feed. NIRM has been proved to be an essential tool in the strategy aiming to tackle the detection of MBM in the frame of the BSE epidemic (Piraux and Dardenne, 1999; Baeten et al, 2001; Baeten and Dardenne, 2001). The principal limitation of this technique is the sequential collection of the spectra (particle by particle) which has been solved by the introduction of the NIR imaging technology (Baeten and Dardenne, 2002).

4.2 Detection of meat and bone meal in feedstuffs

Since 2001, a method based on NIR imaging is developed to detect animal ingredient particles in compound feeds (Baeten and Dardenne, 2002; Gizzi et al., 2003; Michotte Renier *et al.*, 2004). This NIR imaging system allows the analysis of about 400 particles in 5 minutes. Figure 6 presents the NIR image at 1380 nm of four materials from vegetal and animal origin (i.e. compound feed without MBM, mammals meal, poultry meal and fish meal). Each material used is a mixture of 8 different individual samples. Figure 6 shows that, thanks the images obtained with the NIR camera, the animal ingredients can be easily discriminated from the vegetal ones.

The simultaneous analysis of hundreds or thousands of spectra using a near-infrared imaging system has the advantages of the speed and sensitivity that requires a screening method. The first results indicated that the NIR imaging method has a limit of detection about 0.1 % (depending on the number of particles analysed), and allows the discrimination between most of the fish and terrestrial particles. Combined with the recent chemometric method, SVM (Support Vector Machines), used as classification algorithm, the NIR imaging method has proven to be promising for the future (Fernández Pierna et al., 2004a). One of the main advantages of this NIR imaging methodology is that it is a non-destructive method and that can be used in combination with classical microscopy or other techniques in order to get additional information about the particles analysed. Moreover, this method has been applied with success not only on the raw particles, but also on the particles coming from the sediment fraction. The NIR imaging methods have been tested on a wide diversity of compound feeds (with MBM in a range of 0.1% to 8 % and also free of MBM) showing results with a level of false positives and false negatives inferior to 5 % (Fernández Pierna et al., 2004b). NIR imaging could be also applied to give an indication of the origin of animal ingredients presented in contaminated food. Figure 7 presents the NIR images at 1210 and 1360 nm of four animal materials (bovine and pig, poultry, feather and fish meal). Figure 8 presents also another important advantage of the NIR imaging method that, in addition to the spectroscopic information, the morphologic structure of the analysed particle can be obtained. The figure is a NIR image at 1480 nm of about 400 particles of compound feed with feather meal particles. The feather meal particles (in white) are clearly visible (Baeten et al., 2004).

4.3 Detection of the vegetal source of feed ingredients

NIR imaging spectroscopy has been also applied for the complete screening of feedstuffs in order to detect and quantify all feed ingredients included in a compound feed. Figure 9 presents two NIR images at 1480 nm that demonstrates the potential of the method to discriminate different vegetable feed materials. Figure A includes beet, rape seed, linseed and wheat materials; while Figure B includes beet, lucerne, soya and corn materials (Fernández Pierna et al., 2004b).

5. Conclusion

The application of NIR imaging to the remote control and monitoring of agriculture, the analysis of food products as part of the food chain quality and safety control, as well as the control of compound feeds at the ingredient particles level has been briefly reviewed in this chapter. The benefits of NIR imaging technology for the monitoring of the agro-food products are obvious and will increase in the next years. At the early stage main of the effort was concentrated to the exploration and the development of new applications. Now, NIR imaging techniques are in continuous evolvement and are introduced into new fields. We assist, for instance, to the development of full-automated systems for the control of agro-food products where the extraction of the useful data that contribute to the application and the rejection of the voluminous data that may cause confusion remain the main challenges.

6. List of figures

Figure 6. Analysis of mixtures of vegetal feed, mammals meal, poultry meal and fish meal by NIR imaging. NIR image at 1380 nm. (Source : Walloon Agricultural Research Centre, Belgium).

Figure 7. Analysis of processed animal proteins (a = bovine and pig; b = poultry; c = feather; d = fish) by NIR imaging. Figures A and B show the NIR images at 1210 nm and 1360 nm respectively. (Source : Walloon Agricultural Research Centre, Belgium).**Figure 8.** Detection of feather meal in compound feed by NIR imaging. NIR image at 1480 nm. (Source : Walloon Agricultural Research Centre, Belgium).

Figure 9. Analysis of processed vegetal meals (a & e = beet; b = rape seed; c = linseed; d = wheat; f = lucerne; g = soya; h = corn) by NIR imaging. NIR images at 1480 nm. (Source : Walloon Agricultural Research Centre, Belgium).

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