

Using real-time quality measurement to maintain and increase value across the grain supply chain

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Abstract. To manage quality across a supply chain to the standard required by sophisticated markets requires equally sophisticated real-time monitoring technologies that are universal, cheap, simple to use, rapid, reliable and require minimal sample preparation. Feedback from industry indicates that a successful technology will be robust and cheap enough to be used at grain receival silos. Appropriate monitoring is essential for identifying variety, identifying food safety hazards, preserving identity, and enhancing and maintaining value. Currently, several technologies may meet these requirements. These technologies represent horizons of opportunity: near infrared spectroscopy (NIRS) is a current industry-adopted technology that can be developed further, digital imaging (DI) is a technology that is suitable for industrial applications in its current form, and ‘aromasensing’ has the capacity to meet the required criteria in the future.

Introduction

Agrifood system quality is increasing in importance on a global scale (Whitehead 1995; Orriss and Whitehead 2000). In Australia, the food industry has a strong record of quality assurance, in particular in the export sector (Peters 1998). The management of quality across agrifood supply chains to the standard demanded by sophisticated markets requires equally sophisticated real-time monitoring technologies. New technologies have become available to automate and improve the accuracy of many quality measurements in the food industry (Gunasekaran 1996). These methods promise to be universal, cheap, simple to use, rapid, reliable and require minimal sample preparation. Currently, several commercially available technologies either have the potential to, or already, meet these requirements. These include spectroscopy technologies such as near infrared spectroscopy (NIRS), digital imaging (DI) techniques and detection of volatile organic compounds ('aromasensing'; 'electronic nose', or 'eNose'). These technologies represent horizons of opportunity: NIRS is a current, industry-adopted technology that can be further adapted to new situations, DI is a technology that is suitable for industrial applications in its current form, and aromasensing is a longer-term proposition that has the capacity to meet the criteria listed above.

Using NIRS to measure grain quality in storage

NIRS is widely used in the agricultural food sector for measuring the composition of foods (Frankhuizen 1992;

Kays et al. 2000), to check for adulteration (Ding and Xu 2000) and for determining product quality (e.g. Fumiere et al. 2000). In Australia, grain is routinely segregated based on moisture and protein contents determined by NIRS (Ronalds and Miskelly 1985). These applications have gained wide acceptance and are well known and understood throughout the industry. However, NIRS is capable of delivering rapid measurement of a much wider range of parameters of importance to the grain supply chain.

Batten (1998) states: "The limits to the application of NIRS are not readily evident and...the technique is only limited by the range of ideas suggested by its proponents." Applications have been developed for detecting insects in grain and flour (Baker et al. 1999; Ridgeway and Chambers 1999; Perez-Mendoza et al. 2003), identifying waxy and hard wheat phenotypes (Norris et al. 1989; Delwiche and Graybosch 2002), feed grain quality (Wrigley 1999), malting quality of barley (McGill 1989; Lu et al. 2000), gliadin and glutenin contents of flour (Wesley et al. 2001) and many others.

The effects of storage conditions on grain processing properties are of major importance to the Australian grain handling industry. It would be of considerable advantage to the industry if the changes that occur in storage could be measured and predicted. NIRS would be the ideal technology to achieve this, yet no research has been carried out on the effect of grain storage on NIR spectra. Also, if the measured NIR spectra of grain samples depend on the period of postharvest storage, there will be important practical implications for the practice of NIRS calibration.

To address these problems, a Grains Research and Development Corporation (GRDC) funded project carried out by the CSIRO Stored Grain research Laboratory and

The Bread Research Institute of Australia (BRI Australia Ltd) commenced in November 2002. The project aims to develop a NIRS method for rapid, non-destructive assessment of the quality of stored grain. NIRS scans from 2001–2002 storage trials of wheat, barley and canola were analysed to determine if the spectra had changed over the storage period. The criterion for changes in NIR spectra applied was for the average root mean square of difference RMS(C) at 1100–2500 nm between samples before and after storage to be greater than that between repeated measurements ('repacks') of the same sample (Osborne et al. 1999). In other words, if the RMS(C) between control samples and stored samples is greater than the RMS(C) between repacks of the sample, it is likely that storage has had an effect on the NIR spectrum of the sample.

The RMS(C) values of stored wheat are shown in Table 1. RMS(C) values greater than the repack error were

most noticeable at higher storage temperatures and moisture contents. For canola (Table 2) and barley (Table 3), similar trends were observed. These early results suggest that the spectra of grain do change in storage. The relationship between changes in spectra and grain quality changes will be further investigated in storage experiments, and NIRS measurements will be compared to traditional grain quality measurements.

Digital imaging for grain quality assessment

Digital imaging, also referred to as machine or computer vision, is a technology that began in the 1960s (Brosnan and Sun 2002). Since then, it has developed into a rapidly expanding field with more than 1000 papers published annually (Sonka et al. 1999). The technology is well

Table 1. Average root mean square of difference, RMS(C), at 1100–2500 nm of wheat samples collected during the 2001–2002 harvest and stored under controlled conditions for 12 months.

Storage temperature (°C)	Moisture content (%)	Storage time (months)				
		RMS(C) 1100–2500 nm; micro d(log/R)/dl units	3	6	9	12
20	11.0	Repack	410	285	530	584
	13.5		835	635	607	652
25	11.0		458	400	461	428
	13.5		709	920	825	963
30	11.0		892	839	973	1060
	13.5		1789	1884	2007	2069
	11.0	207				
	13.5	291				

Table 2. Average root mean square of difference, RMS(C), at 1100–2500 nm of canola collected during the 2000–2001 harvest and stored under controlled conditions for 9 months.

Storage temperature (°C)	Moisture content (%)	Storage time (months)			
		RMS(C) 1100–2500 nm; micro d(log/R)/dl units	Repack	3	6
20	6			956	1211
	7			1454	1785
	8			1249	1472
25	6			1004	1437
	7			1697	1916
	8			1661	2162
30	6			1436	1942
	7			1917	2637
	8			2927	3472
	6	485			
	7	419			
	8	394			

established in areas such as medical and technical diagnostics and automatic manufacturing, and is of increasing importance in product quality inspection in the agrifood sector (Timmermans 1998; Sun 2000; Chen et al. 2002). The technology has also been used for grain quality assessment and grading of wheat for many years, including variety identification and classification (Majumar et al. 1997; Paliwal et al. 2003), and differentiation between hard and soft wheats (Zayas et al. 1996), damaged kernels (Luo et al. 1999), and screenings (Paliwal et al. 2003). DI methods have also been developed for the detection of insects and other foreign materials (Ridgway et al. 2002) and for the assessment of other commodities such as oats (Hall et al. 2003).

Systems analyse grain on the basis of size, shape, texture and colour of the grain (Luo et al. 1999; Chen et al. 2002). Subtle changes in the CIE colour values of the seed coat occur during storage under Australian conditions, and such changes are readily measured with colorimeters. Figure 1 shows the shifting colour values of barley stored under controlled conditions. DI systems which provide colour measurements may be usable to quantify such changes, and it is important that such variations are taken into consideration when calibrations are applied to grain at receival and again at out-turn.

Actual and potential applications of DI systems in Australia include variety identification, detection of mould contamination, admixture of other grains, detection of grain defects such as blackpoint and sprouting, and detection and identification of weed seeds and insects. Instruments which claim to meet the demands of the Australian industry are now available (e.g. Foss Cervitec™ and DuPont™ Canada Acurum™). There are very little published data on the usability of DI for grain grading at Australian receival sites.

Extensive independent scientific testing will be required to validate the technology and to successfully integrate DI with other technologies.

Aromasensing in the grain industry and along the supply chain

There is a large number of predominantly laboratory-based applications for the use of aromasensing in the food industry, and some progress has been made towards introducing this technology to the grain industry. The ability of aromasensing to detect and differentiate microbial contamination has been demonstrated (e.g. Keshri and Magan 2000; Keshri et al. 2002; Olsson et al. 2002). This reflects the growing concern over mycotoxin contamination of grain worldwide. The concept of detecting invertebrate storage pests in grain has been validated by Ridgeway et al. (1999), who showed that mites can be detected in wheat at infestation levels relevant to the industry. The measurement of a range of other grain quality parameters, including the potential use of instruments in industrial settings, has been described (Gardner and Bartlett 1998; Evans et al. 2000).

Using an instrument such as the α Fox 3000 electronic nose (alphaMOS France), differences between types of grain are readily detected (Figures 2 and 3). In response to the need for development of applications suitable for Australian conditions, a GRDC-funded research project carried out by Food Science Australia in cooperation with CSIRO Divisions of Entomology and Plant Industry has been focusing on how this technology could benefit the Australian grain supply chain. It was found that instruments (α Fox 3000™; alphaMos, France and zNose™ 7100 Flash GC; EST, USA) could discriminate between

Table 3. Average root mean square of difference, RMS(C), at 1100–2500 nm of barley collected during the 2000–2001 harvest and stored under controlled conditions for 9 months.

Storage temperature (°C)	Moisture content (%)	Storage time (months)				
		Rpack	1.5	3	6	9
20	10			406	450	
	12			378	368	411
	14			371	316	472
25	10			377	381	
	12			496	439	423
	14			490	417	563
30	10		496	439	397	
	12		375	386	475	717
	14		422	590	663	790
	10	155				
	12	170				
	14	207				

samples of grain with different quality characteristics and storage histories. Greatest differences were observed with highest moisture content and storage temperature, consistent with findings from viability tests. Experiments with storage pests indicate that high concentrations of insect volatiles are easily detectable. Experiments with fumigated grain suggested that the aroma-profile of wheat is altered by such treatments. Based on these findings and work reported in the literature, electronic nose technology appears to show the potential to detect insects, quality changes, varietal differences, characteristic odours and chemical residues in stored grain.

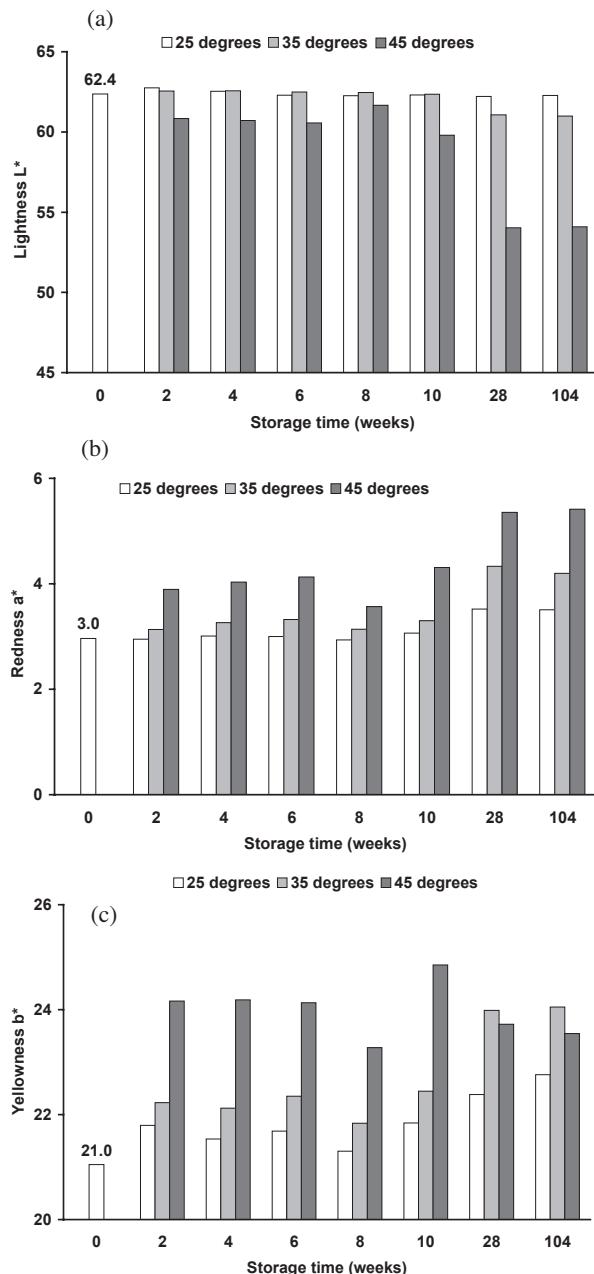


Figure 1. Changes in the colour of whole barley (Minolta colour meter) stored under laboratory conditions for 104 weeks at three different temperatures: (a) lightness L*; (b) redness a*; (c) yellowness b*.

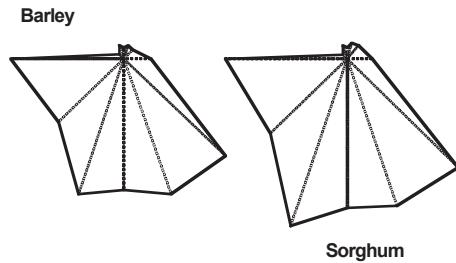


Figure 2. Radar plots of barley and sorghum showing differences in detector responses to volatile compounds produced by grain types.

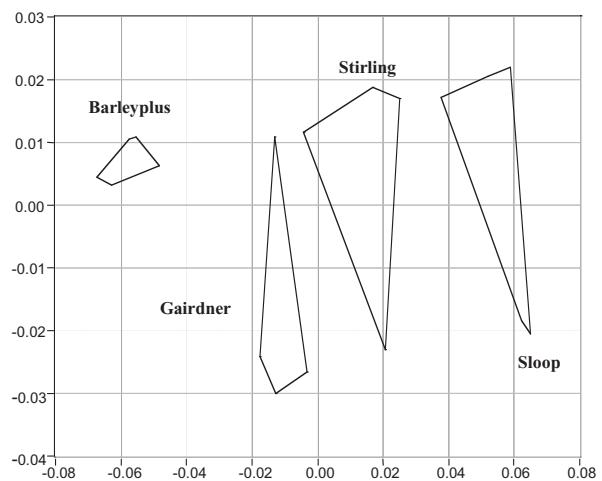


Figure 3. Principal component analysis scores plot showing clusters of the volatiles of four barley varieties analysed with the Fox 3000 electronic nose. The separation of clusters in different regions of the plot implies distinct volatile profiles.

The way forward: short-, medium- and long-term outcomes

The changes that currently shape the grains industry are strongly driven by shifting market demands on the quality of grain, which underpins the grain supply chain. Waning consumer confidence in the safety of food, and the growing complexity of supply chains, has made it prudent to be able to monitor the quality and safety of grain as it moves along the chain. In the short term, product-specific applications that measure product quality in real-time using existing technologies are needed. NIRS, DI and aromasensing can meet some of these needs. In the medium term, applications built on existing technologies, but using novel methods of sample delivery which allow them to be used in a wide range of industrial situations, should be developed. Such applications should be suitable for actively controlling industrial processes. Thinking longer-term, novel methods of sample delivery, detection and data analysis should be developed into universal technologies with multiple market applications which can

assure the quality of supply chains in real-time, provide complete identity preservation, and drive superior engineering controls for targeted product delivery. The industry should therefore partner with research organisations to develop highly parallel, real-time, quality measurement technology that can be used to make appropriate management decisions that maintain and increase value across a supply chain.

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