6:5 Note on near infrared reflectance of minced beef using the Silsoe Moisture Meter

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Introduction

There is a requirement for rapid, non-destructive, non-contact physical methods for determining the composition of meat and meat products for use in research or quality control laboratories and for industrial process control by continuous in-line monitoring.

Several papers report that measurements on near infrared surface reflectance may be used to estimate the composition characteristics of emulsified, homogenised or ground meats, specially prepared in the laboratory (Ben-gera and Norris, 1968; Kruggel et al., 1981; Martens et al., 1981; Lanza, 1983). The instruments employed in the above reports (Neotec Scanning Spectrocomputer and the Technicon InfraAlyzer) require the sample in a special chamber and are thus unsuitable for continuous in-line monitoring.

The Silsoe Moisture Meter (Beaconsfield Instrument Company, Beaconsfield) was recently developed to provide a robust, non-contact method for measuring the moisture content of cut or chopped material passing on a conveyor close to a measuring head.

The purpose of this work was to assess the precision of infrared reflectance measurements for determining the composition of commercially prepared minced beef without further homogenisation with a view to assessing the potential of the Silsoe Moisture Meter for in-line monitoring of the fat and moisture contents of minced beef.

Description of instrument

The Silsoe Meter is designed to measure intensities at four pre-specified wavelengths (670, 940, 1300 and 1450 nm) reflected from materials passing on a conveyor below a sensing head and to display a quantity:

$$P = A+B\ (C.S1450 + D.S1300 + E.S670)/S940$$

S1450, S1300, S940 and S670 are the intensities of the reflected signals at each wavelength and A, B, C, D and E are pre-selected calibration constants. The value of P, and individual intensity and reference values, are available as an RS232 output from the device.

Materials and methods

Thirty nine samples of minced beef, ranging from 2.5 to 5 kg each; were purchased from 10 family butcher shops in the Avon area over a one-month period; each shop was visited at least three times on different days. Three subsamples of mince were packed into glass petri dishes 11 cm diameter and 1.5 cm deep, and their surfaces pressed flat. They were covered immediately and only exposed for measurement on a turntable rotating at 1 rpm with the axis of the sensing head angled at 30° to the normal to the surface. The separation of the sample surface and front face of the sensing head was set at 2 cm. Readings were averaged over 1 minute in a circle approximately 3.5 cm diameter. A 'white' surface was measured under the same experimental conditions and further subsamples were removed from each batch of mince and analysed for moisture and extractable fat by freeze drying followed by vacuum drying, and Foss-let analysis respectively.

The N intensities S_{iw} at wavelength w (w = 670, 940, 1300, 1450 nm) were averaged to give the four mean intensities S_w and the ratio of the intensities at two wavelengths j and k averaged to give R_{jk} as follows:

$$S_w = \frac{1}{N}\sum_{i=1}^{N} S_{iw} \quad ; \quad R_{jk} = \frac{1}{N}\sum_{i=1}^{N} \frac{S_{ij}}{S_{ik}}$$

At each wavelength w, the intensity S_w (here the mean of the three sub-samples) was normalised to the corresponding intensity of the 'white' surface to give the four apparent reflectance measurements used in the analysis. Means of the apparent reflectances and reflectance ratios, averaged over three sub-samples, were examined for correlations with the % fat and % moisture in the samples.

Results

A basic description of the data is presented in Table 1. The apparent reflectance of the mince surfaces was highest at 670 nm, lowest at 1450 nm and reflectance at 940 nm was higher than at 1300 nm (Table 1, Figure 1). There was an appreciable uncertainty in the intensity measurements even for the standard 'white' surface averaged over 1 minute (sd of 6 to 7 for intensity readings ranging from 245 to 301, Table 1). Standard deviations of the intensities reflected from the surfaces of minced beef showed higher percentage uncertainties, even after allowing for the effect of sample (Table 1).

At all wavelengths, there were positive correlations between apparent reflectances and fat proportions and negative correlations between apparent reflectances and moisture contents (Table 2, Figure 1).

Since the geometry remained constant between samples, the individual intensities (S670, S940, S1300 and S1450) also yielded correlations with % extractable fat and % moisture of very similar magnitude to the corresponding correlation coefficients quoted in Table 2 (maximum difference in corresponding r was 0.01).

The correlation coefficients for % extractable fat and % moisture versus the ratio R_{jk} were found to differ by no more than 0.06 from corresponding correlations with R_{kj}. The ratios S1450/S940, S1300/S940 and S670/S940 yielded markedly different correlations with chemical analysis data (Table 2). Of the three, S1450/S940 was the best predictor and S670/S940 the worst. However, S1450/S670 gave the highest correlation of all the ratios and no ratio gave as good a correlation as the apparent reflectance at 1450 nm (Table 2, Figure 2). The constituents of the commercially prepared minces were outside our control so that some samples may have contained additional ingredients and Figure 2 records the negative correlation between extractable fat and moisture in the experimental samples.

The residual standard deviation (rsd) of the prediction of % moisture (2.67%), based on the apparent reflectance at 1450 nm, was significantly reduced in a multiple regression with the reflectance at 1300 nm which gave an rsd of 2.55% (Table 3). Inclusion of the reflectance at 940 nm did not significantly improve the precision of a regression based on the reflectance at 1450 nm and 1300 nm. Multiple regression did not significantly improve the precision of predictions of % extractable fat based on the reflectance at 1450 nm alone (rsd = 2.98%).

A multiple correlation of % extractable fat with the intensity ratios S1450/S940 and S670/S940 (rsd = 3.30%) was of comparable predictive value to the

TABLE 1 Basic statistics of the data for 39 samples of minced beef

	Composition of mince*		Intensities+ reflected from the surface of							
			Minced Beef				White tile**			
	% water	% extractable fat	670 nm	940 nm	1300 nm	1450 nm	670 nm	940 nm	1300 nm	1450 nm
Mean	63.1	17.7	188	129	77	19	301	274	245	251
Standard deviation (between samples)	4.8	6.2	23	20	16	5	7	6	6	6
Residual standard deviation (after allowing for effect of sample)	1.0	.5	10	7	4	2	-	-	-	-

	Apparent Reflectance of mince surface++				Intensity ratios for mince surface					
	670 nm	940 nm	1300 nm	1450 nm	670 nm / 940 nm	1300 nm / 940 nm	1450 nm / 940 nm	1300 nm / 670 nm	1450 nm / 670 nm	1450 nm / 1300 nm
Mean	.53	.40	.27	.065	1.47	.59	.15	.41	.101	.25
Standard deviation	.07	.06	.06	.018	0.10	.05	.02	.05	.018	.02
Residual standard deviation (after allowing for effect of sample)	.03	.02	.02	.006	.026	.013	.008	.012	.006	.011

* % on wet basis
++ ratio of intensities sample/white tile x 0.85 (see ** for explanation of factor of .85)
+ arbitrary units
** actual reflectance of 'white' tile used in this experiment was 0.85 at 670 nm

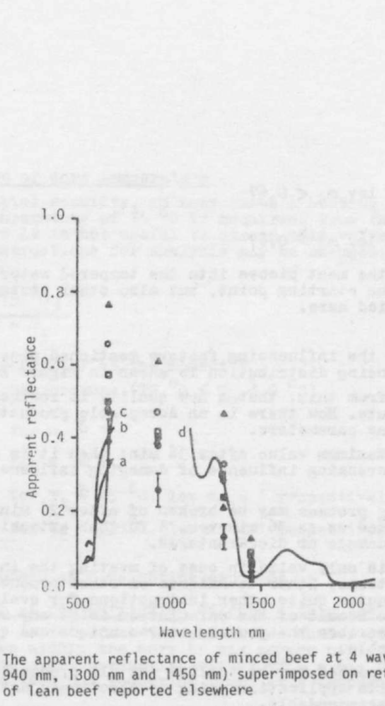

Figure 1 The apparent reflectance of minced beef at 4 wavelengths (670 nm, 940 nm, 1300 nm and 1450 nm) superimposed on reflectance spectra of lean beef reported elsewhere

Curves a, b and c taken from MacDougall (1977) are of beef M. Semimembranosus:

(a) vacuum packed
(b) exposed to 1000 lux for 1 hour
(c) exposed to 1000 lux for 7 days
(d) beef (Lanza, 1983)

The apparent reflectance of minced beef at wavelengths of 670, 940, 1300 and 1450 nm is shown at 6 compositions.

Symbol	% moisture	% extractable fat
□	53.1	30.5
○	55.5	25.4
△	69.2	10.4
■	66.8	15.5
●	63.9	19.6
▲	53.2	34.8

Ɪ Apparent reflectance of minced beef adjusted to zero lipid content. Error bars indicate ± standard error.

TABLE 2 Linear correlation between NIR Silsoe Meter readings and the chemical composition of 39 samples of minced beef

	% water		% extractable fat	
	r	rsd	r	rsd
Apparent reflectance at 670	-.65	3.72	.69	4.55
" " 940	-.71	3.42	.78	3.95
" " 1300	-.76	3.19	.84	3.41
" " 1450	-.84	2.67	.88	2.98
Intensity ratio 670/940	.41	4.44	-.50	5.43
" " 1300/940	-.55	4.07	.63	4.85
" " 1450/940	-.75	3.23	.75	4.12
" " 1300/670	-.66	3.66	.76	4.06
" " 1450/670	-.82	2.81	.85	3.34
" " 1450/1300	-.76	3.18	.69	4.54

r = correlation coefficient

rsd = residual standard deviation

TABLE 3 Multiple correlations between NIR Silsoe Meter data and the chemical composition of minced beef

	% water		% fat	
	r	rsd	r	rsd
Apparent reflectance at 1450 nm + Apparent reflectance at 1300 nm	.86	2.55	NS	-
Intensity ratio 1450/940 + Intensity ratio 670/940	.81	2.87	.85	3.30

r = multiple correlation coefficient

rsd = residual standard deviation

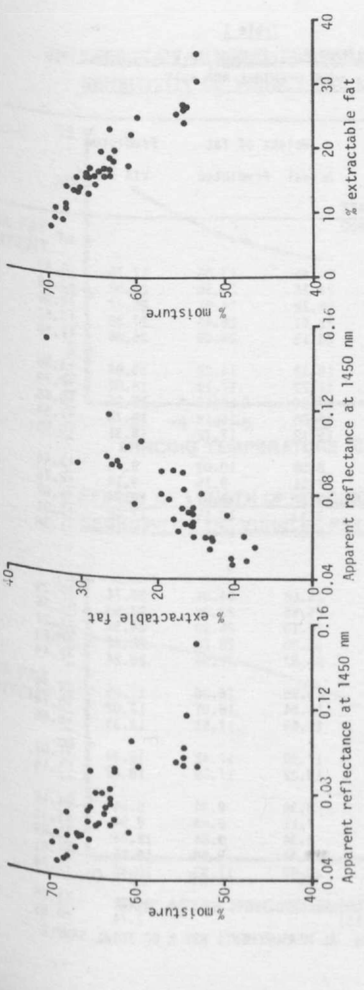

Figure 2 Relationships between the chemical composition and the apparent infrared reflectance at 1450 nm of flat surfaces of minced beef

(a) % moisture
(b) % extractable fat
(c) interrelationship between % moisture and % extractable fat

Data for 39 samples

linear correlation with the ratio S1450/S670 (rsd = 3.34%) but less precise than predictions based on the apparent reflectance at 1450 nm, recorded above.

Discussion

The precisions of the correlations recorded in this experiment for commercial minced beef of a wide range of comminution and inhomogeneity are worse than precisions quoted for specially prepared emulsified, homogenised, or ground samples (Martens et al., 1981; Kruggel et al., 1981 and Lanza, 1983). For example very precise correlations have been reported by Lanza (1983), who, using a Neotec model 6350 Scanning Spectrocomputer, selected reflectance values at four wavelengths in the range 1100 to 2500 nm to predict the % fat and % water in emulsified samples of pork and beef. Lanza quotes rsd ranging from .2 to .3% for fat and from .5 to .6% for moisture whereas corresponding values for this work are 3.0% and 2.6% respectively (see Tables 2 and 3). Lanza also used a mathematical transformation of the spectra to obtain second derivatives with respect to wavelength since this was thought to reduce variations due to particle size, sample temperature and sample compaction and to break the inter-correlations between reflectance data at different wavelengths. Furthermore Lanza used a computer analysis of the spectra to determine the four best wavelengths for prediction and the wavelengths for moisture prediction differed from those for fatness. Our wavelengths, not chosen specifically for meat, were predetermined by the manufacturers for use on a range of moist materials and excluded 1920 nm where a minimum in the reflectance spectra of pork and beef is reported.

Our results are more comparable with those of Kruggel et al. (1981), who, using a Technicon Infra Analyser to measure specially prepared ground lamb, found that the rsd of the multiple correlations with reflectances at six wavelengths ranged from 2.4 to 2.6% for fat and 1.9 to 2.0% for water. Corresponding precisions for his 'pooled' data were 3.0% and 4.6%.

Of the four wavelengths studied, 1450 nm contributed the most to fatness and water predictions. This corresponds to a maximum in the absorption spectrum of lean meat attributed to O-H vibrations of water (Ben-gera and Norris, 1968) and a minimum in the reflectance spectrum (Lanza, 1983). At this wavelength the surface of minced beef has an apparent reflectance in the region of 2% (Figure 1) and a high sensitivity and repeatability is required to allow discrimination between samples showing small differences in reflectance at low levels. The intrinsic uncertainty of the instrumental readings probably contributed appreciably to the scatter of the data about the regression lines (the repeatability of the intensity measurements of a uniform surface was about ± 1 unit ± 2%, Table 1). Separate contributions to the scatter were caused by the intrinsic uncertainty of the chemical analysis data (Table 1) and by sub-sampling variations in the reflectance data due to sample inhomogeneity and other intrinsic errors peculiar to the meat surface, such as surface roughness and instrument-surface distance variations.

The results of this experiment indicate that continuous measurement of near infrared reflectance of a product passing close to a sensing head has potential for in-line composition analysis of meat in industrial process control. However the standard Silsoe Moisture Meter that was tested in this experiment would only be suitable for rough composition assessments and before the full potential of the method could be realised it would be necessary to optimise instrumental factors such as to increase the sensitivity and repeatability of the measurements on surfaces with a low reflectance.

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