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Mature-ripe tomato spectral classification according to lycopene content and fruit type by visible, NIR reflectance and intrinsic fluorescence

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RESEARCH ARTICLE

Abstract

The human health benefits of carotenoids and phenolic compounds present in fruits and vegetables such as tomato, the second most consumed vegetable in the world, are well established. But characterisation of fruits is a tedious task. Tomato, with a thin, transparent and edible exocarp is interesting as a case-study for rapid characterisation by spectroscopy. An experiment was conducted to rapidly measure tomato lycopene content and classify mature-ripe tomatoes according to fruit-type (beef, vine or pink type) in a non-destructive way. A total of 1,560 fruits were collected from the market, retailers and producers. Three solid-state spectrometers were used; two for measurement of reflectance (visible; Vis: 450-750 nm and near-infrared; NIR: 600 to 1,150 nm) and one for capture of intrinsic fluorescence at either 275 or 400 nm excitation. Best results for lycopene content were obtained by Vis+NIR on beef-type fruits; coefficients of determination (r^2) = 0.65, ratio of data standard deviation to root mean square error of prediction (SDR) = 1.80. A model based on the three fruit types yielded a r^2 of 0.64 and a SDR of 1.59. These results allowed for lycopene classification within three categories (<30, 30-50 and >50 mg/kg) with a correct classification rate of 73.6%, and no confusion between high and low lycopene content fruits. Fluorescence at EX 400 nm was also efficient at measuring lycopene (r^2=0.59, SDR=1.51) but there was no advantage adding fluorescence to Vis or NIR data. The three types of fruits were well separated by Vis spectroscopy (80.3% correct classification). Adding EX 400 nm data to the model improved the classification rate to 87.9%. Intrinsic fluorescence at EX 275 nm clearly separated pink from the beef and vine-type fruits. Solid-state spectrometers thus have a potential for semi-quantitative classification of mature-ripe tomato fruits.

Keywords: colour, discriminant analysis, rapid characterisation, spectroscopy

1. Introduction

Lycopene, a deep red pigment found in tomato, watermelon and other fruits has long been studied for its potential role in preventing chronical diseases (Story *et al.*, 2010; Wang, 2012) as well as its use in food and nutritional supplements (Viuda-Martos *et al.*, 2014). Although the exact molecular mode of action of lycopene is still unknown, ingestion of tomato products decreased risk for cardiovascular diseases (Story *et al.*, 2010), atherosclerosis (Palozza *et al.*, 2012), and certain types of cancer (Aydemir *et al.*, 2013; Cohen, 2002; Rao *et al.*, 2006). It might also reduce the incidence of other diseases such as Alzheimer disease (Min and Min, 2014), asthma (Wood *et al.*, 2008), the age-related macular degeneration (Cardinault *et al.*, 2005) although some inconclusive results have also been reported (Schleicher *et al.*, 2013). Lack of undoubted evidences supporting the relation between lycopene intake and reduced risk of diseases may be due to variability in lycopene bioavailability and uptake, lycopene conformation, metabolic products of lycopene and other bioactive compounds in tomato (e.g. flavonoids, vitamin C, provitamin A). In the case of breast cancer, the antiproliferative activity of lycopene during the cell-division cycle has been characterised (Takeshima *et al.*, 2014). The main mode of action of lycopene and other carotenoids has been related to its antioxidant properties. It

is, for instance, an efficient singlet oxygen quencher (Stahl and Sies, 1996), while metabolic products of lycopene may alter gene expression (Erdman *et al.*, 2009; Tan *et al.*, 2014). The antioxidant properties of lycopene have already been tested in the context of food processing. Various practical applications in the meat industry have been developed (Viuda-Martos *et al.*, 2014). For instance, Sánchez-Escalante *et al.* (2003) found that addition of lycopene-rich tomatoes has a significant antioxidant effect on beef patties.

It is in the context of a high consumption rate of tomato, raw or processed (Canene-Adams *et al.*, 2005), that the numerous studies on the potential health benefits of lycopene are conducted. There are, however, no rapid methods of lycopene analysis adapted to the high volumes being sold on markets. There is a need for a fast and non-destructive method to assess tomato lycopene for sorting, grading and standardising its content for the food industry and consumers.

Since lycopene strongly absorbs blue light, there is a good potential for direct content analysis by spectroscopy on processed food (Pék *et al.*, 2014) or raw fruits (Fish, 2012). Previous studies on rapid tomato lycopene analysis have focused on visible-near-infrared (Vis-NIR) spectroscopy, a logical choice for a coloured pigment that is mostly located in the peel (Vinha *et al.*, 2014). Clément *et al.* (2008) have obtained precise results with a scanning laboratory instrument (r^2=0.98). Their data set included fruits from the market whose maturity ranged from mature green to overripe. Kusumiyati *et al.* (2008), using a portable instrument, obtained a less precise assessment (r^2=0.65). This suggests that methodological approaches have a significant influence on models quality.

Front-face fluorescence spectroscopy is a promising approach for the measurement of signals relating to the presence of aromatic compounds in food (Clément *et al.*, 2010). One of the interests of the method comes from its ease of use. Powerful light sources in the ultraviolet (UV) to blue wavelength range are available for excitation of molecules having conjugated carbon chains. Carotenoids are known to be fluorescent. In lipid globule suspensions, they absorb light at about 400 to 525 nm, with maximum fluorescence emission between 520 and 650 nm (Gillbro and Cogdell, 1989). Any presence of chlorophyll has a strong impact on overall fluorescence, with a major emission band at longer emission wavelength: 670 nm. Quantum yield of carotenoids fluorescence is low, being 100 to 2,000 times lower than chlorophyll (Kleinegris *et al.*, 2010).

Including immature fruits in a dataset increases the variability of lycopene content in the experimental set-up, and consequently the model prediction performance, expressed in terms of SDR, which is the ratio of dataset standard deviation / root mean square error of prediction (RMSEP). Rapid analysis is, however, particularly important when fruits are fully mature, i.e. when lycopene content is highest. Therefore, for practical purposes, it is needed to develop models within the range of expected lycopene content in mature-ripe, market-ready fruits. Since model development for single fruit types would result in reduced applicability within the industry, the robustness of equations needs to be assessed. This research work aimed at determining the potential of Vis-NIR spectroscopy, with or without data from fluorescence spectroscopy, to predict lycopene content in tomatoes of three fruit types. We focused on the use of miniature optical fibre-based equipment and multiple fruit types and varieties at a level of maturity close to consumption, i.e. when lycopene content is highest.

2. Materials and methods

Sampling and physico-chemical analyses

A total of 1,560 tomato fruits were sampled in Quebec, Canada, from September 2009 to June 2010. Weight (g), colour and firmness were measured on each individual fruits. Colour was measured on four spots along the fruit's equator. Measurements were made using a USB4000 spectrophotometer (Ocean Optic, Dunedin, FL, USA) configured for the CIELAB scale with daylight (D65) and a 2 degrees observer. Fruit firmness was assessed at four equatorial points using a mechanical rheometer (Bareiss HP, Oberdischingen, Germany; Clément *et al.*, 2008). Lycopene content was measured on a composite sample of 6 fruits of the same type and variety that were collected simultaneously at the same site and had a seemingly equivalent colour. There were 261 such 'lots'. One quarter of each fruit was kept after longitudinal cut, and they were kept frozen at -20 °C. Before analysis, composite fruits samples were thawed for 24 hours at 4 °C and homogenised with a blender for 1 minute in an opaque container to minimise pigments degradation (Pesek and Warthesen, 1987). Lycopene content measurement was performed by precisely weighing about 0.4 g of tomato homogenate in three 40 ml amber vials (Cole-Parmer Canada Inc., Montreal, QC, Canada), according to the method of reduced volumes of organic solvents developed by Fish *et al.* (2002). The upper hexane phase was then sampled and the absorbance was read at 503 nm with a UV-Vis spectrophotometer (model 8453; Hewlett Packard, Palo Alto, CA, USA). Lycopene (mg/kg) = (A503×31.2)/quantity of tissue used (Fish *et al.*, 2002). The result for each sample was an average of the three vials.

Spectroscopy

For reflectance measurements, fruits were positioned on a holder with a 22 mm diameter hole in the middle. A tungsten-halogen lamp (LS-1; Ocean Optics, Dunedin, FL, USA) was placed 76 mm below the sampler. Two

optical fibre probes were positioned at 45 degrees with regard to the plane of the sampler, at a 20 mm (Vis) and 25 mm (NIR) distance from the sample. Measurements were conducted in a laboratory bench-top dark room. Optical fibres channelled reflected light towards two solid state spectrometers (USB4000; Ocean Optics). One of them collected from 180 nm to 890 nm (450 to 750 nm kept for partial least squares (PLS) analysis) and the other 600 to 1,200 nm (600 to 1,150 nm kept). The combined Vis+NIR spectra covered 450 to 1,150 nm with a cut-off at 630 nm. A second set-up was based on the use of a higher sensitivity spectrometer for fluorescence measurements (Maya 2000Pro; Ocean Optics). The optical fibre probe was positioned vertically, 25 mm below a sampler with a 10 mm diameter hole above which fruits were positioned. Two light emitting diodes (LED) at a 45 degrees angle were used alternatively as excitation sources, a 275 nm LED (Sensor Electronic Technology, Inc., Columbia, SC, USA) and a 400 nm LED (Roithner LaserTechnik GmbH, Vienna, Austria).

Data analysis

Lycopene content was predicted using PLS-regression with the Unscrambler 10.3 software (Camo, Oslo, Norway). Model performance was determined by separating the dataset in two, with 75% of lots randomly selected for calibration and the rest for validation. Criteria selected were RMSEP, coefficients of determination (r^2) for calibration and validation, and model bias. The ratio of variable standard deviation to RMSEP (SDR), sometimes referred to as 'RPD' (Slaughter *et al.*, 2003) was calculated, as an additional means to evaluate model performance. For discriminant analysis, a principal component analysis was first implemented on each spectral dataset (reflectance and fluorescence), on mean-normalised data. Scores on the 8 first principal components were used as input data for linear discriminant analysis performed by XLStat (Addinsoft, Paris, France). A stepwise procedure was used to select only the most significant variables that could differentiate the factors under study (categories of lycopene content or type of fruits). An analysis of variance using Proc GLM (SAS Institute Inc., Cary, NC, USA) was implemented at each wavelength to determine if differences in percentage reflectance among fruit types were significant.

3. Results and discussion

Fruits under study were all ripe, with positive a* values in all cases (Table 1). L* values, an indicator of maturity (Clément *et al.*, 2008), were almost the same for all three fruit types. The b* value was considerably lower for pink-type fruits, a feature that has already been documented (Ballester *et al.*, 2010). Beef-type fruits had the highest lycopene content, followed by vine-type and pink fruits. Variability of lycopene content was good, with a coefficient of variation between 22 and 26% for all fruit types, but expectedly lower than what has been published when using a wider range of maturities (59%; Clément *et al.*, 2008). Firmness of all fruits was comparable. As expected, Vine-type fruits were smallest, as compared to the two other tomato types (Table 1).

The reflectance spectra of mature tomatoes are relatively simple. Reflectance is low from 450 to 575 nm. Then it increases to 35-42% reflectance between 625 and 900 nm, making the fruit appear red. There are two major absorbance bands around 975 nm, and 1,135 nm (Figure 1). Reflectance is clearly higher for pink fruits between 450 and 475 nm, as compared to the two other fruit types. Average reflectance between 625 and 1,050 nm is highest for beef-type fruits and lowest for pink fruits (Figure 1). These differences are highly significant in these spectral regions (P<0.01).

Table 1. Main characteristics of fruits under study.[1]

	Beef-type		Vine-type		Pink-type	
	Average	CV (%)	Average	CV (%)	Average	CV (%)
No. of lots[2]	122	–	116	–	23	–
L*	53.75	3.7	53.23	4.0	53.18	4.0
a*	17.16	11.5	16.07	11.3	15.70	16.2
b*	12.27	22.8	11.54	20.1	6.67	40.5
Lycopene (mg/kg)	42.25	26.4	40.27	23.9	37.41	22.4
Weight (g)	194.01	21.0	151.14	17.3	185.42	20.9
Firmness (relative)	56.33	13.4	57.10	14.9	54.75	7.3

[1] CV = coefficient of variation; L* = lightness; a* = green/red colour axis; b* = blue/yellow colour axis.
[2] One lot comprised 6 fruits.

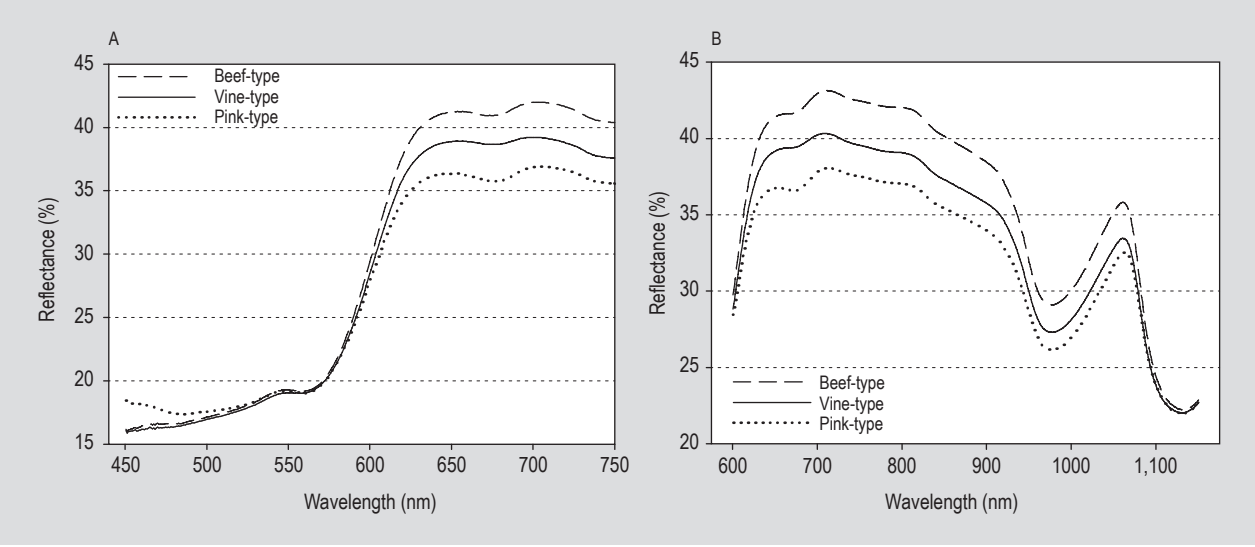

Figure 1. Average reflectance profiles obtained from the (A) visible spectrometer and (B) visible-near-infrared spectrometer.

Rapid lycopene measurement on ripe fruits using miniature solid state equipment is possible, with a RMSEP between 6.1 and 8.1 mg/kg (Table 2). This corresponds to a ratio of data standard deviation to RMSEP (SDR) reaching 1.80 and a maximum r^2 (validation) of 0.75. According to Saeys *et al.* (2005), quantitative models based on spectroscopy can be considered when a SDR of 2.50 and a r^2 of at least 0.82 are obtained. They consider that models that can distinguish high and low values are obtained when validation r^2 are between 0.50 and 0.65 and SDR is between 1.50 and 2.00. The method used in this study is thus suitable for rapid classification of tomatoes, with an aim to identify low and high lycopene content fruits, which may have a different appeal to the consumer.

Various pre-treatments, spectral ranges, and combination of spectra were tested. The best model was obtained when calibrating with beef-type fruits alone (Table 2, Figure 2). Two avenues were compared to verify robustness with regard to fruit types. First, including all three fruit types in the model dataset provided good results (validation r^2=0.66, SDR=1.59, Table 2). Second, using vine-type or

Table 2. Tomato lycopene content as predicted by visible, near-infrared and fluorescence spectroscopy (Ex 275 and 400 nm). n=122 (beef-type), n=23 (pink-type) and n=116 (vine-type). Averages of 4 spectra per fruit, and 6 fruits per lot.

Spectra (nm)	Best pre-treatment[1]	Prediction dataset[2]	Validation dataset	No. of factors	RMSEP[3]	r^2 calibration[4]	r^2 validation	Bias	SDR[5]
450-1,150	MN	B, V, P	random	6	6.32	0.64	0.66	-0.23	1.59
450-750	D2	B, V, P	random	6	6.39	0.69	0.65	-0.20	1.57
525-670	MN	B, V, P	random	4	6.63	0.60	0.63	-0.20	1.52
600-1,150	D2	B, V, P	random	6	6.74	0.68	0.62	-0.39	1.49
450-1,150	MN	B	random	4	6.07	0.65	0.75	2.97	1.80
450-1,150	MN	B	vine-type	7	6.52	0.72	0.54	-1.04	1.71
450-1,150	MN	B	pink-type	3	5.79	0.65	0.59	-1.14	1.92
EX 275	none	B, V, P	random	5	8.07	0.68	0.45	-0.8	1.24
EX 400	none	B, V, P	random	6	6.69	0.59	0.62	-0.13	1.51
Vis + EX 275	MN	B, V, P	random	6	6.49	0.64	0.64	-0.46	1.55

[1] MN = mean normalisation; D2 = second derivative.
[2] B = beef-type; V = vine-type; P = pink-type.
[3] RMSEP = root mean square of error for prediction.
[4] r^2 = coefficients of determination.
[5] SDR = ratio of dataset standard deviation/RMSEP.

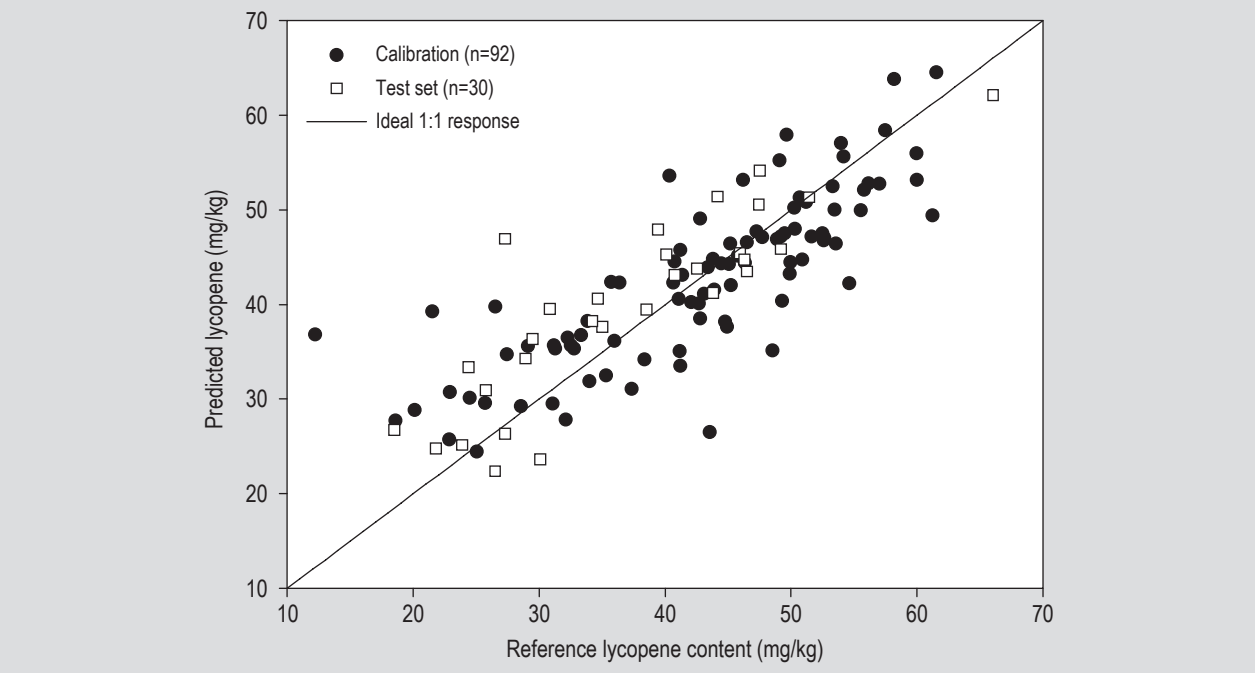

Figure 2. Prediction of lycopene content of beef-type fruits by visible + near-infrared spectroscopy using a solid-state device. Validation test set results: r^2=0.75, RMSEP=6.07 mg/kg.

pink-type fruits as independent validation datasets with the beef-type model also provided suitable results. SDR obtained were 1.71 and 1.92 for vine-type and pink-type fruits, respectively (Table 2). It is noteworthy that bias was small, as compared to RMSEP, in all cases except for the beef-type model (bias=2.97; Table 2). The model based on all three fruit types has the advantage of including inherent variability of tomatoes, while the model based on beef-type fruits performed best with an adjustment; the number of factor was not the same for best results on vine-type (7) or pink-type fruits (3) (Table 2). This suggests that in general, lycopene assessment models are robust with regard to tomato fruit types, but including variability within the model has the additional benefit of being more widely applicable. This represents an advantage, since tomato variety or type is generally not identified on fruits found on the market.

Of the various spectral regions that were tested, the largest sequence, from 450 to 1,150 nm was best (based on SDR; Table 2). However, spectral information relating to lycopene content is clearly centred around 600 nm, as shown by regression coefficients from Vis+NIR spectra (Figure 3). Hence, it is the slope of the increasing reflectance signal between 580 and 620 nm that slightly varies according to the lycopene content of tomato fruits (Figure 1 and 3). The 525-670 or 450-750 sequences obtained from the Vis spectrometer provided better results than the 600-1,150 nm spectrum from the NIR spectrometer (Table 2).

The set-up used involved taking measurements on fruits that were positioned on a fruit holder with a 22 mm diameter hole. With varying fruit sizes and shapes, the exact distance between the probe and the fruit surface was slightly variable. This may explain why mean normalised data and/

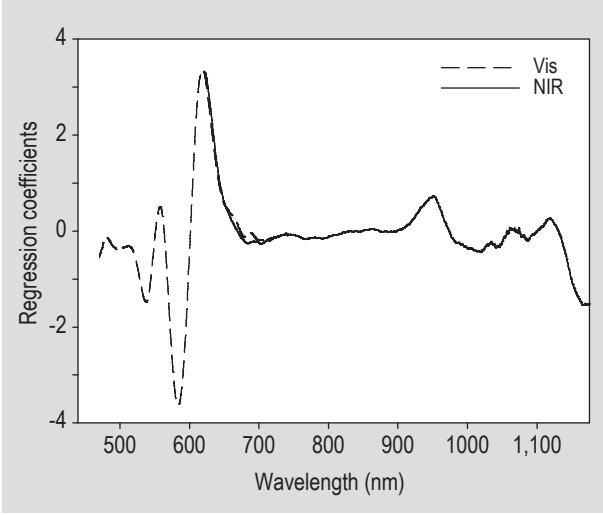

Figure 3. Regression coefficients of partial least squares-models for spectral analysis of lycopene content obtained from combined visible (Vis; 450-750 nm) and near-infrared (NIR; 600-1,150 nm) spectrometers with 3 latent variables. Models based on mean normalised spectra including all three tomato fruit types.

or second derivatives were most effective models (Table 2). These two pre-treatments tend to minimise amplitude related variability of spectra, and provide flexibility in terms of measurement geometry.

Results found in the literature for lycopene analysis by spectroscopy are variable. For instance, Clément *et al.* (2008) obtained a root mean square error of cross-validation of 3.15 mg/kg (r^2=0.98). They used a laboratory scanning spectrometer. Taking measurements directly in a tomato slurry made from pre-mature to mature fruits, and using an optical fibre probe, Choudhary *et al.* (2009) obtained a standard error of prediction of 5.1 mg/kg and a r^2 of 0.93. However, Kusumiyati *et al.* (2008) have obtained results for lycopene analysis by NIR (SDR=1.67-1.69) comparable to what was found in this study. They worked with highly variable maturity levels and a single variety.

To assess the capacity to classify fruits in three categories according to the lycopene content (<30 mg/kg, 30-50 mg/kg, and >50 mg/kg), a discriminant analysis was conducted using Vis+NIR (450-1,150 nm) spectral data. A principal component analysis was first implemented on Vis+NIR spectra, and scores on the 8 first principal components were used to develop the discriminant function. The stepwise procedure selected components 1, 2, 3, 5 and 7 as significantly discriminant. The overall correct classification rate was 73.6% (Table 3). Expectedly, there was some confusion between adjacent categories (low-medium or medium-high), as there were no natural groupings in lycopene content among fruits. The 30-50 mg/kg was chosen to encompass 75% of the fruit population, and there were an equivalent number of fruits with 'low' and 'high' lycopene content. None of low lycopene content fruits were classified as having a high content, the opposite also being true (Table 3). Ninety percent of medium lycopene content fruits were correctly classified. Hence, there is a potential for rapid screening of tomato fruits according to lycopene content, on a semi-quantitative basis. High lycopene content fruits could be automatically tagged to comply with some quality standards. Rapid tomato characterisation would also allow for inclusion of more precise data on lycopene content in nutrition fact sheets.

Intrinsic fluorescence patterns of ripe tomato fruits were simple, consisting of a single bell-shaped signal with minor asymmetries (Figure 4). Pink-type tomatoes produce a strong fluorescence emission signal at EX 275

Table 3. Confusion matrix for the classification of tomato lycopene content in three categories by visible + near-infrared spectroscopy (450-1,150 nm), using factorial discriminant analysis (n=261; low: <30; medium: 30-50; and high: >50 mg/kg). Cross-validation results.

		Predicted			Total	% correct
		Low	Medium	High		
Actual	Low	16	27	0	43	37.2
	Medium	8	156	9	173	90.2
	High	0	25	20	45	44.4
	Total	24	208	29	261	73.6

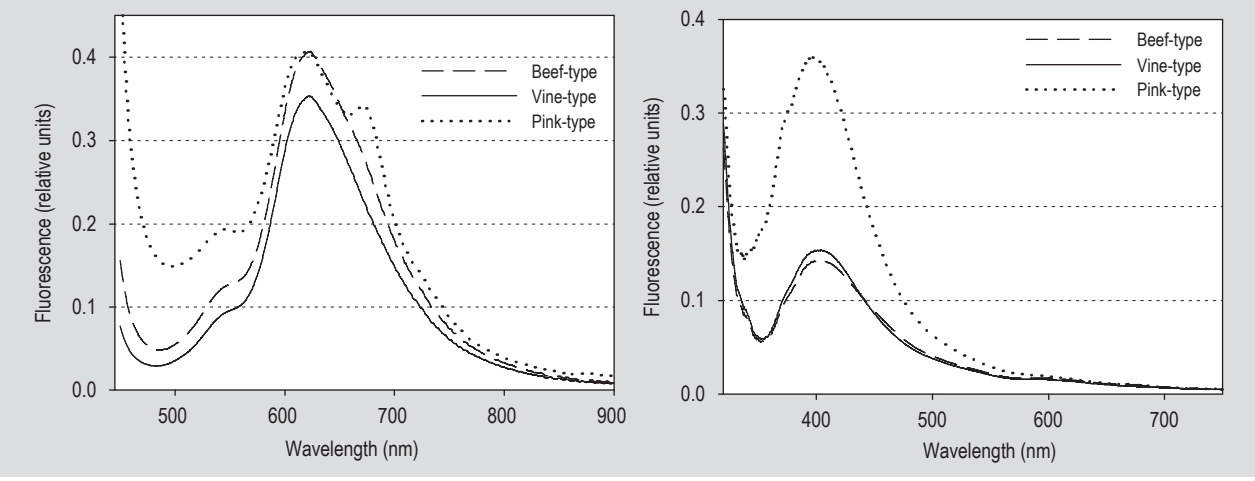

Figure 4. Average fluorescence profiles of beef-, vine- and pink-type tomatoes at Ex 275 (left) and Ex 400 nm (right); n=728 (beef), n=694 (vine), and n=138 (pink).

nm, as compared to Beef or vine-type fruits (Figure 4). Differences were comparatively less at EX 400 nm. Ballester *et al.* (2010) have demonstrated that pink-type tomatoes lack the pigment naringenin chalcone in the fruit peel, a yellow coloured flavonoid. Clearly higher fluorescence levels at EX 275 nm and emission around 400 nm suggest that some other phenolic compound may be present in the peel of Pink fruits, in large concentration, as compared to beef and vine-type tomatoes. Lai *et al.* (2007) suggest that fluorescence at EX 300 nm and emission (EM) around 425 nm is caused by flavonoids, and EX 280/EM 300 nm corresponds to anthocyanins.

Predicting lycopene content from intrinsic fluorescence measurements was possible, although less precise than using Vis or NIR spectroscopy (Table 2). Of the two excitation wavelengths tested, EX 400 nm resulted in the best model, with a RMSEP of 6.69 mg/kg. EX 275 nm had a good calibration model that was not robust, since validation statistics were poor (Table 2). Rapid analysis of pigment content from fluorescence data makes sense, as lycopene and other carotenoids have highly conjugated carbon chains facilitating electron movement and fluorescence. Quantum efficiency of carotenoids fluorescence is known to be low (Bondarev, 1997; Gillbro and Cogdell, 1989). But increased solid-state instruments sensitivity and availability of powerful light sources make low quantum yield readings easier to record. This was shown by Kleinegris *et al.* (2010). They were able to localise carotenoid globules *in vivo* in green algae with confocal laser scanning microscopy. Mixing reflectance and fluorescence data did not improve results of lycopene rapid spectroscopic measurement. The best model obtained combined Vis (525-670 nm) to EX 275 nm (Table 2). Performance was better than fluorescence alone, but it was not better than using the 450-750 or 450-1,150 nm reflectance ranges (Table 2). Hence, there was no synergetic advantage mixing reflectance and fluorescence.

Carotenoids content influences colour of fruits, as these pigments readily interact with visible light. This was shown for corn (Rios *et al.*, 2014). In the present study, predicting colour variables from Vis spectral data was expectedly precise, with cross-validation r^2 of 0.97, 0.97 and 0.98 for L*, a* and b*, respectively. But predicting lycopene content from colour data was not possible, as r^2 values were very low. Combining the three colour variables to predict lycopene content did not improve prediction, with a r^2 of only 0.15. Hence, in mature tomato, the capacity of the human eye to distinguish high or low lycopene content from colour perception has limits that can be improved by use of rapid spectroscopy measurements.

While pink-type tomatoes can be recognised by their particular tint, beef- and vine-type fruits are different cultivars comparable in colour. An attempt was made to distinguish fruit type by means of spectral profiles. Vis spectroscopy distinguishes pink-type tomatoes with success (97.8% correct classification, Table 4). There is a difficulty distinguishing beef- vs vine-type fruits (76.8 and 80.6% correct classification, respectively). Adding fluorescence at EX 400 nm improved overall correct classification from 80.3 to 87.9% (Table 4, Figure 5). This is mostly due to a better separation of beef- vs vine-type fruits (Table 4). The capacity to correctly classify about 85% of beef- vs vine-type fruits must be considered with the perspective of similar fruit phenotypes, and natural

Table 4. Confusion matrix for the automatic classification of tomato type using visible (Vis; 450-750 nm; top), or Vis + fluorescence at Ex 400 nm (bottom). Cross-validation results.

		Predicted (Vis)			Total	% correct
		Beef	Vine	Pink		
Actual	Beef	559	166	3	728	76.8
	Vine	131	559	4	694	80.6
	Pink	0	3	135	138	97.8
	Total	690	728	142	1,560	80.3
		Predicted (Vis+Ex 400)			**Total**	**% correct**
		Beef	**Vine**	**Pink**		
Actual	Beef	617	109	2	728	84.8
	Vine	78	616	0	694	88.8
	Pink	0	0	138	138	100.0
	Total	695	725	140	1,560	87.9

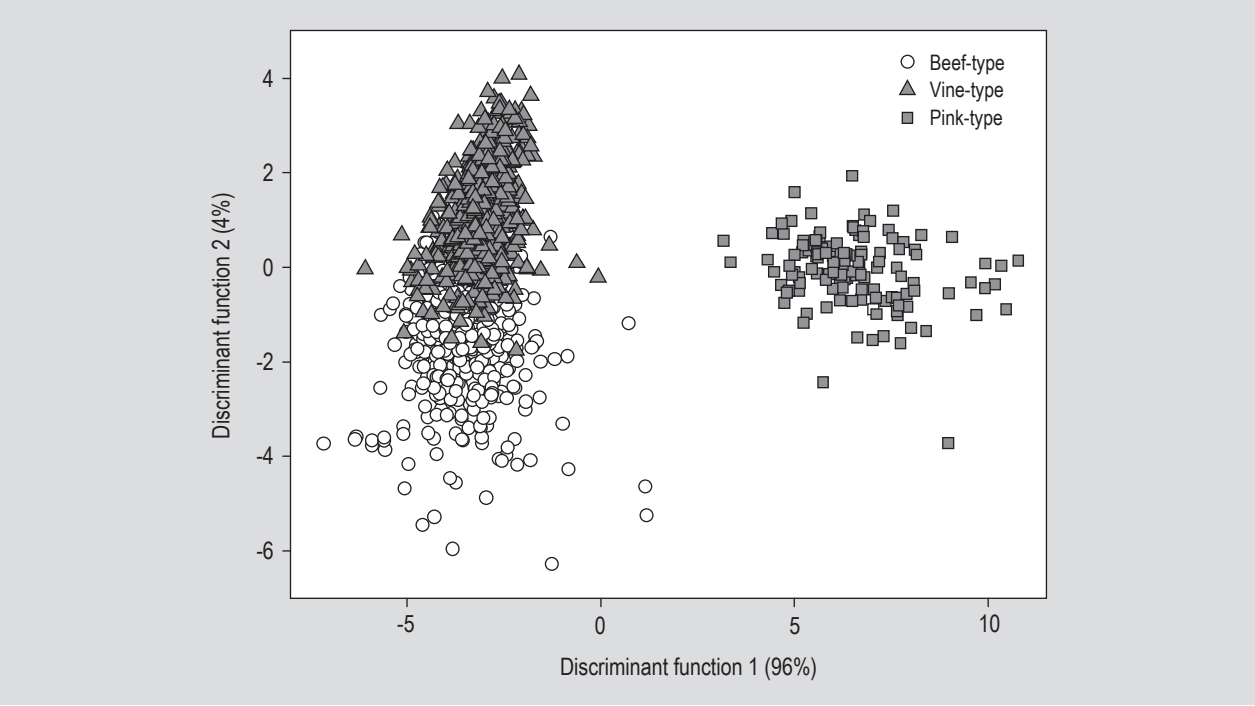

Figure 5. Factorial discriminant analysis of tomato types using visible reflectance + fluorescence at Ex 400 nm; n=732 (beef-type), n=696 (vine-type) and n=132 (pink-type). Cross-validation results.

variability of cultivars within both fruit groups. Hence, only slight differences in pigment and phenolic profiles in the epicarp are sufficient to distinguish fruit types by spectral analysis. The capacity of simple spectroscopy readings to distinguish varieties that are very much similar in composition has been tested on various foods. Chen *et al.* (2014) were able to distinguish white and albino tea, which are very much similar in appearance and difficult to discriminate with existing analytical tools. Such methods can lead to authentication of food products, such as milk, that can be adulterated with various proteins and thickeners (Zhang *et al.*, 2014). While NIR remains a very common method to discriminate sample foods, fluorescence is increasingly used for authentication purposes (Seetohul *et al.*, 2013).

4. Conclusions

Tomato is a fruit with a very thin peel with exposed phytonutrients, which is conveniently explored by light. Results indicate that using fibre optic spectrometers can rapidly classify mature-ripe fruits from various cultivars and types, in a heterogeneous market situation. For classification of fruits according to lycopene, a single miniature spectrometer with a reduced 525-670 nm range that has a grating blazed in that region should give optimal result. Semi-quantitative, but robust results are obtained within a test population representative of postharvest fruit condition, with fruits of seemingly comparable colour. The CIELAB colour scale does not allow for classification of tomatoes with high or low lycopene content; spectral analysis being clearly superior. It was found that intrinsic fluorescence at fruit surface is readily measured, despite a low quantum yield of pigments other than chlorophyll. At EX 275 nm, fluorescence clearly distinguishes pink-type tomatoes, in accordance with a unique phenolic profile. The approach may thus provide data to characterise fruit phenolics such as flavonoids, which are both coloured and fluorescent. At EX 400 nm, lycopene analysis is almost as accurate as Vis or NIR reflectance. But EX 275 nm does not provide robust assessments of lycopene. Reflectance is still a preferable approach to lycopene assessment, as it necessitates simpler and less sensitive hardware. However, combining reflectance and fluorescence measurements did show potential for multiple parameter measurements. Fruit types can be distinguished automatically with an 80.3% success rate using reflectance data. Correct classification increases to 87.9% when combining reflectance and fluorescence, suggesting a synergy of information.

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