



Maturity prediction of intact bell peppers by sensor fusion



Timea Ignat*, Victor Alchanatis, Ze'ev Schmilovitch

Department of Agricultural Engineering, Volcani Center, Agricultural Research Organization, Bet Dagan 50250, Israel

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ABSTRACT

The objective of this study is to present a fusion of non-destructive sensor outputs and a fusion of destructive reference parameters. The sensors used in the present work were spectrophotometers in the VIS–NIR and SWIR spectral range, hyperspectral imaging in the visible range, relaxation and ultrasonic tests, and colour measurement. As reference parameters, the following were used: total soluble solids, dry matter, osmotic potential, ascorbic acid, total chlorophylls, carotenoids content, coefficient of elasticity measured in compression and rupture mode. The fusion procedure was based on the combination of sensor outputs and the combination of reference parameters. Linear and non-linear regression methods were applied for model establishment.

Multi-sensor models were found to be better than the single sensor models based on the significantly lower root mean square errors of cross validation values for all tested cultivars and all reference parameters. By the reference parameter fusion a new combined quality index was developed in order to evaluate the global quality of the produce. With the new combined quality index not only the comprehensive quality of the produce could be predicted but also its maturity stage, which can serve as a basis for better decision of harvest schedule; as the new index correlate with the physical property change during growth.

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1. Introduction

Quality measurement of fresh produce is a challenging task as quality is a combination of different features. Some of these features are visual appearance (freshness, colour, shape, size, decay, defect), texture (turgidity, crispness, firmness), nutritional value (vitamin A and C) and flavour (taste and smell). Most of these features can be determined either by human or by different vision systems, destructive, non-destructive methods or chemical analysis (Kader, 2002). At the present practice if the quality determination is done mechanically, then the way to distinguish between samples is based on one or a few single attributes, like colour, total soluble content or texture. This way of differentiation between samples draws final conclusion on the produce quality based on limited information. Generally a qualified person with sufficient experience is capable to differentiate between samples of different quality as only human sensation integrates the visual appearance, texture and flavour. The drawback of human classification of produce based on its quality is slow, time consuming and its repeatability is low (Steinmetz et al., 1999b). The sensor-based

simulation of such a complex sensation is a challenging task. In order to take such a challenge a well established sensor fusion has to be carried out. The fusion methodology suggested by Steinmetz et al. (1999b) is a process containing eight steps. It starts with the examination of different properties of the produce. The next step is to choose the appropriate destructive (reference) and non-destructive tests for the measurement of the produce properties, followed by the selection of the best fitting chemometric procedure. The suggested process by Steinmetz et al. (1999b) contains the evaluation of the system and possibilities for its improvement.

Table 1 presents an overview of research works which were conducted in the recent years in the field of agriculture, focusing on the quality prediction of fruits and vegetables. As it is presented in the overview, there are no standard rules in making fusion. In the realization of fusion a wide range of sensors are used online or in the training set with wide spectrum of statistical regression, classification methods and learning machines in order to predict the quality of the produce. In each cited case it was concluded that sensor fusion yielded a considerably (5–20%) lower error of regression or classification. This fact encourages the continuation of this research field to be used in wider produce range and as a possible tool in the complex quality prediction.

This work presents a study of sensor fusion for quality detection of bell peppers and a novel approach of quality attributes merging, resulting to a new combined quality index.

* Corresponding author. Address: Institute of Agricultural Engineering ARO, The Volcani Center, P.O. Box 6, Bet Dagan 50250, Israel. Tel.: +972 3 968 3459; fax: +972 3 968 3504.

E-mail address: timea@volcani.agri.gov.il (T. Ignat).

Table 1
Overviews of prediction of quality parameters by fusion.

Agricultural product	Predicted component	DT method	NDT method	Statistical method	References
Apple	Firmness, soluble solids content (SSC)	Magness-Taylor, digital refractometer	Acoustic firmness sensor, Bioyield tester, VIS/SWIR, Online hyperspectral scattering	PLS	Mendoza et al. (2012)
Pepper	Shrinkage, firmness, colour	Texture analyzer	Weight image acquisition	ANN	Mohebbi et al. (2011)
Pepper	DW, TSS	Conventional method, refractometer	Ultrasonic, relaxation, colour	PCR	Ignat et al. (2010)
Tomato	Colour, firmness		Colorimeter, impact and acoustic test	Bayesian classifier	Baltazar et al. (2008)
Apple	Bruise		Electronic nose, surface acoustic wave sensor	PC A, PNN	Li et al. (2007)
Apple	Firmness, soluble solids content (SSC)		Acoustic impulse resonance frequency sensor, VTS/NTR	PLS, PLSDA	Zude et al. (2006)
Apple	Colour, shape, weight size, defects	Manual measurements	Colorimeter	Fuzzy logic	Kavdir and Guyer (2003)
Eggplant	Colour, length, girth, bruises		Image processing	ANN	Saito et al. (2003)
Peach	Firmness, SSC, acidity, chlorophyll, carotenoids, anthocyanins	Penetrometer, refractometer, laboratory measurement	MMS1-NTR, electronic nose	PLS, PLSDA	Natale et al. (2002)
Peach	SSC, titratable acidity, firmness	Refractometer, titration, penetrometer	VIS-NIR, non-destructive impact response	k-Means clustering, stepwiseDA	Ortiz et al. (2001)
Apple	Sugar	Refractometer	Vision system, NIR	MNN	Steinmetz et al. (1999a)
Orange	Size, weight firmness, TSS, acidity, colour	Refractometer, titration	Vision system, impact firmness sensor, NIR, colorimeter	PC A, MLR, FDA, NN	Steinmetz et al. (1997)

2. Materials and methods

2.1. Plant materials

The experiments were carried out from December 2009 to February 2010, and included fruits of three cultivars of different colours, obtained from three commercial greenhouses, in Ein Tamar, Israel (30°57'27" North, 35°23'56" East). The cultivars were 'Ever Green' (green variety), 'No. 117' (yellow variety), and 'Celica' (red variety). The pepper samples chosen for the study were marked during their flowering stage and fruits were picked nine times along the growing season: at 1 week intervals during the 9-week growing period from the 34th day after anthesis (DAA) until full ripening (88th DAA), and when fully grown. Each picked batch of each cultivar comprised 20 fruits, i.e., a total of 180 fruits of each cultivar. Shortly after picking, the fruits were cooled and kept in an air-conditioned laboratory at 23 °C. The fruits were first subjected to spectral measurements by scanning at the half-length of one side of each pepper. Samples were then taken from the same location, for destructive determination of chlorophylls and carotenoids content. The measurements ranges along the growing period were 3.2–9.3% for the total soluble solids, 1.3–169.5 mg 100 g⁻¹ for the ascorbic acid, 0.0004–0.1163 mg g⁻¹ for total chlorophylls content and 0.0024–0.27 mg g⁻¹ for the carotenoids content.

2.2. Non-destructive measurements

Shortly after picking, each fruit's colour was measured by a colorimeter. A Minolta Data Processor DP-301 of Chroma Meter CR-300 series was used for colorimetric measurements. Colour indices were taken at half-length and two sides of each pepper fruit. The first measured side was where all the measurements were conducted, and the second side was the opposite one. The two measurements were averaged. The following colour indices were recorded: Lightness (L), Chroma (C) and Hue (h).

Spectral reflectance of pepper fruits was measured with a USB2000 (Ocean Optics, Dunedin, FL, USA) mini spectrometer, with spectral range: 350–1000 nm; grating: 600 lines blazed at 750 nm;

optical spectral resolution at full-width at half-maximum was 7.6 nm. A bidirectional reflection probe (BIF600-UV-VIS, Ocean Optics, Dunedin, FL, USA) was used, with a bundle of six fibres to carry the incident light from the LS-1 Tungsten Halogen Light Source (Ocean Optics, Dunedin, FL, USA) and with one fibre to collect reflected light towards the spectrometer. The spectrometer yielded 2048 data points with a spectral sampling interval of 0.5 nm. The bidirectional reflection probe did not touch the sample. The bidirectional probe was mounted on the top of a hollow cone, 15 mm from the sample surface. The hollow cone (black Delrin® Polyoxymethylene), 25 mm in diameter at the base, 15 mm in height and with a slope of 45° shielded the optical assembly and the measured surface of the fruit from ambient radiation. Because of high noise in the ranges of 350–477 nm and 950–1000 nm, the spectral range of the USB2000 spectrometer was reduced to 477–950 nm (1446 data points).

Further spectral measurements were obtained with a Liga SWIR spectrophotometer (STEAG Micro Parts, Dortmund, Germany) with a single-directional optical fibre mounted on the top of a hollow cone attachment (30 mm in diameter, black Delrin® Polyoxymethylene) as described above. The detection probe was 15 mm from the sample surface. The light source of this instrument, too, was an LS-1 Tungsten Halogen lamp. The incident beam from the light source fell perpendicularly onto the fruit sample, and the radiation reflected at an angle of 45° was collected. Altogether 128 data points within an 850–1888 nm sampling interval were acquired in each scan, with optical spectral resolution of 8.1 nm.

Both configurations were calibrated with a Spectralon, WS-1-SL standard white ceramic background disc (Ocean Optics, Dunedin, FL, USA). The spectral measurement systems were arranged in diffused reflectance mode for receiving the signals from the peel and flesh of the fruit. The spectrophotometers sampled an area on the circumference of the largest cross-section, perpendicular to the stem-blossom axis. The sampled area of each fruit was scanned 10 times, and the readings were automatically averaged to form a one spectrum signal. The light source was turned-on half an hour prior to spectral acquisition in order to stabilize its output.

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