Nondestructive Determination of Soluble Solids in Tomatoes using Near Infrared Spectroscopy

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NONDESTRUCTIVE METHOD FOR DETERMINING THE SOLUBLE SOLIDS CONTENT OF FRESH WHOLE TOMATOES WAS INVESTIGATED. THE METHOD, BASED ON NEAR INFRARED SPECTROPHOTOMETRIC TECHNIQUES, COULD PREDICT THE SOLUBLE SOLIDS CONTENT OF TOMATOES (r = 0.92, SEC = 0.27 Brix). TOMATOES FROM MORE THAN 30 POPULAR FRESH MARKET CULTIVARS AT STAGES OF MATURITY FROM MATURE GREEN TO Ripe RED FRUIT WERE STUDIED.

KEY WORDS: NONDESTRUCTIVE, NEAR INFRARED SPECTROSCOPY, SOLUBLE SOLIDS, TOMATOES, MATURE

INTRODUCTION


SEVERAL RESEARCHERS HAVE ATTEMPTED TO USE OPTICAL TECHNIQUES TO DEVELOP A NONDESTRUCTIVE MEANS OF ASSESSING TOMATO QUALITY. THE INITIAL PURCHASE DECISION BY CONSUMERS IS USUALLY BASED UPON APPEARANCE AND THE STAGE OF RIENESS IS WELL CORRELATED WITH FRUIT COLOR. THUS, MOST OPTICAL SYSTEMS HAVE BEEN DEVELOPED TO SENSE VISIBLE LIGHT CHARACTERISTICS OF TOMATOES ASSOCIATED WITH THESE ATTRIBUTES (E.G., BIRTH ET AL. 1957; BITTNER AND STEPHENSON, 1968; NATTVETTY AND CHEN, 1980; O'BRIEN AND SARCAR, 1974; WORTHINGTON ET AL., 1976). WATADA ET AL. (1976) USED LIGHT TRANSMITTANCE THROUGH WHOLE TOMATOES TO PREDICT THEIR CAROTENOID (r = 0.97 FOR LYCOPENE, r = 0.95 FOR β-CAROTENE) AND CHLOROPHYLL (r = 0.98) PIGMENT CONTENTS.

NEAR INFRARED (NIR) SPECTROSCOPY HAS BEEN USED AS A RAPID AND NONDESTRUCTIVE TECHNIQUE FOR MEASURING THE SOLUBLE SOLIDS CONTENT (SSC) OF SEVERAL COMMODITIES. DULL ET AL. (1989) APPLIED NEAR INFRARED AT 884 nm AND 913 nm TO DETERMINE THE SSC IN CANTALOUPE. WHEN THE MEASUREMENT WAS MADE ON SLICES OF CANTALOupe THE CORRELATION BETWEEN THE NIR METHOD AND THAT DETERMINED BY HIGH-PERFORMANCE LIQUID CHROMATOGRAPHY WAS −0.97 WITH A STANDARD ERROR OF CALIBRATION (SEC) OF 0.56° Brix. WHEN THE MEASUREMENT WAS MADE ON INTACT CANTALOUPES THE CORRELATION DROPPED TO −0.60 AND THE SEC INCREASED TO 1.67° Brix. DULL ATTRIBUTED SOME OF THE DROP IN CORRELATION TO LIGHT LOSSES THROUGH THE RIND. DULL AND BIRTH (1989) LATER REFINED THEIR NONDESTRUCTIVE METHOD AND APPLYING IT TO HONEYDEW MELONS IMPROVED THE CORRELATION BETWEEN SSC AND NIR MEASUREMENT TO −0.87, HOWEVER THE SEC WAS 1.6° Brix. SLAUGHTER (1995) USED A NONDESTRUCTIVE NIR TECHNIQUE TO PREDICT THE SSC OF INTACT PEACHES AND NECTARINES, r = 0.92 AND SEC = 0.87° Brix. KAWANO ET AL. (1993) USED A CALIBRATION EQUATION WITH 4 NIR TERMS TO PREDICT THE SSC OF INTACT SATSUMA MANDARINS, r = 0.899 AND SEC = 0.28° Brix.


DUE TO THE HIGH CORRELATION BETWEEN SSC AND TOMATO FLAVOR QUALITY THERE IS A NEED TO RAPIDLY AND NONDESTRUCTIVELY DETERMINE SSC TO ASSURE THAT ALL TOMATOES MEET A MINIMUM LEVEL OF ACCEPTANCE. IDEALLY SUCH A SYSTEM COULD DETERMINE THE SSC OF WHOLE INTACT TOMATOES WITHOUT A PRIORI KNOWLEDGE OF CULTIVAR.

THIS RESEARCH STUDIED THE FEASIBILITY OF DETERMINING FRESH WHOLE TOMATO SSC WITH A NONDESTRUCTIVE OPTICAL TECHNIQUE BASED UPON NIR SPECTROSCOPY.

MATERIALS & METHODS

TOMATOES FROM MORE THAN 30 POPULAR FRESH MARKET CULTIVARS (INCLUDING: ARLETTA, BETTER BUSH, CELEBRITY, EARLY GIRL, HEATWAVE, JACKPOT, SUNNY, TANGO, ETC.) WERE HAND HARVESTED IN CALIFORNIA AT STAGES OF MATURITY RANGING FROM MATURE GREEN TO Ripe RED FRUIT. TEN REPLICATE FRUITS OF EACH OF APPROXIMATELY SIX CULTIVARS WERE TESTED WEEKLY OVER A 7-WK PERIOD RESULTING IN A TOTAL OF 400 FRUIT FOR STUDY. SOME CULTIVARS WERE INCLUDED IN THE STUDY TWICE, EACH TIME AT A DIFFERENT MATURITY LEVEL, TO GUARANTEE A WIDE RANGE OF MATURITIES. THE TOMATOES WERE STORED AT 15°C AFTER HARVEST UNTIL READY TO TEST AND WERE EQUILIBRATED TO ROOM TEMPERATURE (24°C) PRIOR TO EVALUATION.

THE OPTICAL ABSORPTION SPECTRUM FROM 400 nm TO 1100 nm WAS MEASURED AT FIVE DIFFERENT LOCATIONS ON EACH FRUIT USING A FIBER OPTIC INTERACTANCE PROBE (FIG. 1). THE PROBE CONSISTED OF A CENTRAL BUNDLE OF SCHOTT GLASS FIBERS 7.6 mm IN DIAMETER SURROUNDED BY A 0.64 mm WIDE CONCENTRIC RING OF SCHOTT GLASS FIBERS WHICH HAD AN OUTSIDE DIAMETER OF 19 mm. THE OUTER RING OF FIBERS WAS SEPARATED FROM THE CENTRAL BUNDLE BY A 5.1 mm THICK METAL BAR. A RAPID SCANNING (1.8 scancsec) SPECTROPHOTOMETER (MODEL 6500, NIR SYSTEMS, SILVER SPRING, MD) CONFIGURED FOR INTERACTANCE MODE WAS INTERFACED TO THE FIBER OPTIC PROBE. AT THE SPECTROPHOTOMETER INTERFACE THE FIBERS IN THE PROBE CORRESPONDING TO THE OUTER RING WERE RECONFIGURED TO ALIGN WITH THE EXIT SLIT OF THE MONOCHROMATOR.
To measure the optical absorption spectrum, each fruit was hand placed on the probe so that the desired fruit location was centered on and in direct contact with the probe. The absorption spectrum was measured at each of five different locations on each fruit in a sequential manner. The first measurement was collected at a random location on the equator of the fruit. The next three measurements were taken on the equator at approximate 90° (i.e. 0.50) from each other in opposite directions, and in direct contact with the probe. The absorption spectrum was measured at each of five different locations on each fruit in a sequential manner. The first measurement was collected at a random location on the equator of the fruit. The next three measurements were taken on the equator at approximate 90°, 180°, and 270° rotations from the initial site. A fifth measurement was taken with the blossom end of the fruit centered on the probe. The average of 250 individual optical scans at each fruit location was stored for later use. A 20.8 mm thick Teflon block was used as the optical reference standard for the system.

Following optical measurement the tissue from each fruit was comminuted in a blender for 60 sec. The soluble solids content of the comminuted tomato was determined using a temperature compensated refractometer. The optical and soluble solids data were then merged and a partial least squares (PLS, Martens and Naes, 1989) regression analysis was conducted using the NSAS software package (version 3.18, NSAS, 1990). To determine any significant differences in the predictive ability of the five locations used for optical measurement, the data from each location were analyzed separately. Preliminary analysis using a trial and error process indicated that for the electromagnetic region studied the wavelength range of 800 nm to 1000 nm would provide the best prediction of soluble solids content using the PLS multivariate calibration technique. PLS calibrations resemble principal component regression models in that regression factors are linear combinations of optical absorbance at each wavelength in the spectral region studied (i.e. 800 nm to 1000 nm). The correct number of regression factors for the PLS model was determined by the minimum mean square error of cross validation, where the calibration data set was split into four subsets of equal size (Martens and Naes, 1989). Cross validation of each of the five calibration models corresponding to the five different fruit locations indicated that as few as 6 PLS factors (for the blossom end location) to as high as 10 PLS factors (for one of the equatorial locations) could be used to predict the SSC. To facilitate direct comparison of the predictive ability of the five locations, five calibration models were developed, one for each location, each using six PLS factors.

Each calibration model was then used to predict the SSC of each fruit using optical data collected at each of the five locations. Residuals between the predicted SSC and the SSC determined by refractometer were compared (Table 1). In general, it would be expected that the average residuals would be lowest when the calibration model developed at a particular location was used to predict the SSC using the optical information from that same location. Results indicate that all five calibration models (including that developed using data from the blossom end) had a significantly (α = 0.05) greater average residual when used to predict the SSC with optical data from the blossom end than from the four equatorial locations. The calibration developed at the blossom end had lower residual values when used to predict the SSC using equatorial data than from the blossom end data. The less reliable results obtained at the blossom end may have been due to physiological differences in the fruit at that location.

**RESULTS & DISCUSSION**

The average absolute value of residuals and standard error values between the NIR predicted SSC and the SSC determined by refractometer were compared (Table 1). In general, it would be expected that the average residuals would be lowest when the calibration model developed at a particular location was used to predict the SSC using the optical information from that same location. Results indicate that all five calibration models (including that developed using data from the blossom end) had a significantly (α = 0.05) greater average residual when used to predict the SSC with optical data from the blossom end than from the four equatorial locations. The calibration developed at the blossom end had lower residual values when used to predict the SSC using equatorial data than from the blossom end data. The less reliable results obtained at the blossom end may have been due to physiological differences in the fruit at that location.
and requires further study. These results indicate that the blossom end should be avoided when attempting to predict SSC using the NIR technique employed here.

The residual values from the four equatorial locations did not indicate consistent differences between the calibrations developed with optical data from these four locations. The standard error of prediction (SEP) for SSC ranged from 0.29°Brix to 0.43°Brix when the calibration developed at one equatorial location was used with optical data from a different equatorial location on the same fruit.

A PLS calibration analysis was conducted to predict the SSC of 100 randomly selected fruit (based upon the average NIR data of four equatorial locations of each, Fig. 2). Cross validation indicated that a calibration model using 12 PLS factors was appropriate, $r = 0.92$ and SEC = 0.27°Brix. Validation results were obtained from application of the calibration model to the remaining 300 tomatoes (Fig. 3). The validation data had a correlation coefficient of $r = 0.89$, a SEP of 0.33°Brix with a bias of -0.05°Brix. These results indicate that use of 12 PLS factors did not lead to overfitting and that the calibration model appeared to be valid. The SEP value based upon an average optical reading from four different equatorial positions was smaller than any of the SEP values shown (Table 1).

**CONCLUSIONS**

NIR SPECTROSCOPIC TECHNIQUES can be used to nondestructively determine soluble solids content of intact tomatoes. The interactance technique had significantly greater accuracy when used at a random position along the equator of the fruit than at the blossom end. In developing high speed sorting equipment for SSC, orientation of the fruit to allow measurement on the fruit equator would be recommended.

**REFERENCES**


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