Determination of tomato quality attributes using portable NIR-sensors

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Abstract As part of a research project a multidisciplinary approach of different research institutes is followed to investigate the possibility of using a commercially available miniaturized NIR-sensor for the determination of tomato fruit quality parameters in postharvest. Correlation of spectra and tomato reference values of firmness, dry matter and total soluble solids showed good prediction accuracy. Additionally the decline of firmness over storage time with respect to storage temperature of tomatoes could be modelled. Therefore, the decline of firmness as an indicator for shelf-life can be predicted using this portable NIR-Sensor.

Keywords: NIR, portable, tomato, brix, firmness, dry matter.

1 Introduction

At the moment, grading and sorting of fresh produce is highly dominated by external and internal quality attributes like colour, fruit texture and sugar content. Some of these requirements are statutory and written down in marketing standards for fresh fruit and vegetables [1]. In order to guarantee internal quality like sweetness and taste of produce, additional testing of internal quality parameters like sugar content or sugar-acid ratio is necessary for certain products alongside these statutory criteria standards. The determination of internal parameters is often time consuming and requires destructive measurement methods. Immediately after harvest the quality of fruits and vegetables changes due to ongoing metabolic processes. Depending on various parameters like fruit maturity, packaging and storage conditions, quality of post harvest produce decays in different time periods. Sensitive fruits like strawberries have a shelf life of only a few days, whereas more robust fruits like apples can be stored for up to nearly one year under appropriate storage conditions. Climacteric fruits like tomatoes underlie post-ripening, which on one hand can lead to longer shelf life, but on the other hand cause alteration of sensorial parameters like taste or haptic. Furthermore, firmness is an important indicator of tomato quality which determines shelf life and influences consumer's acceptance [2]. Tomato is one of the most important fruits cultivated in Germany, with a total percentage of nearly 30 % of Germany's greenhouse production area for vegetables [3] and number one vegetable with respect to per capita consumption [4]. Sugar content, acidity and the acid-brix ratio are internal quality parameters that can help to determine the ripening stage and affect the taste of tomatoes. In the past, various studies were conducted to prove that some of these parameters can be predicted using near-infrared spectroscopy (NIRS) on different tomato varieties [5, 6]. NIRS is well suited for quality control of fresh produce because it is non-destructive and requires little to no sample preparation. Additionally, NIRS techniques can be used as multidimensional predictors to determine various parameters in one work-step. Due to an ongoing technical development and miniaturization in the field of NIR spectrometers, companies are offering small and portable sensors. These devices can be used in numerous applications throughout the agro-food and horticultural industry, as illustrated by dos Santos et al. [7]. The technique of NIR is already applied in sorting and grading machines, especially for high quality produce which are ripened in post-harvest processes (e. g., mango, avocado). In contrast to bulky benchtop devices, these hand-held sensors allow a transfer of NIR techniques from the laboratory to in-field and other applications along the whole horticultural supply chain of fresh produce. In addition to the determination of specific fruit quality parameters, these devices could unlock potential in measuring the maturity or ripening stage of fresh produce with respect to remaining shelf life. A measurement tool which allows the quantification of shelf life could help to reduce the amount of annual food loss of around 11 million tons [8] in Germany. First studies indicate that there is high potential for predicting the quality of fresh fruits and vegetables with portable and miniaturized NIR devices. According to Kusumiyati et al. [9], the use of a portable NIR-device and PLSR analysis proved feasibility of predicting the on-tree firmness of tomatoes with r^2 = 0,88 and a standard error of prediction of 0,09 MPa as well as lightness value L* (r^2 = 0.96, SEP = 3.19) and color value a* (r^2 = 0,98, SEP = 3,13). Some startup companies focus on this development and launch various miniaturized NIR-hand-held devices called food-scanners, promising end-consumers a fast and nondestructive measurement of various food traits like protein, sugar or total energy content [10]. A first study by Kaur et al. [11], which examined the performance of different portable and commercially available spectrometers with respect to the prediction of dry matter, showed promising results for a combined data set of apples, kiwifruit and summerfruit (rp^2 of 0,93-0,95). Subsequent research investigated the on-tree prediction of 'Hass' avocado harvest maturity using the F-750 spectrometer (Felix Instruments) and found suitable prediction models for dry matter (rp^2 = 0.98; RMSEP = 0.25 %) and oil content (rp^2 = 0.96; RMSEP = 1.14 %) [12]. A current study, focusing on the performance of a consumer scale SCiO (Consumer Physics) molecular sensor by Li et al. (2018), found good results for the prediction of total soluble solids in kiwifruit ($RVal^2$ = 0.77; RMSEp = 0.76 %) and potential in classifying feijoa according to maturity and 'Hass' avocado according to ripening stage, whereas the prediction of apple quality was not feasible. In summary, miniaturized NIR devices seem to hold potential in predicting the quality of fresh produce, making it a good method of choice in investigating the feasibility for quality predictions of tomato fruit. At the moment, a key challenge for a successful implementation in supply chain processes is the provision of suitable prediction models of fresh produce. Since different types of produce require specific calibrations, further work is required to investigate predictable fruit quality parameters and to build up data collections, which allow a robust calibration of portable devices. As part of the alliance ″Wir retten Lebensmittel″, initiated by the Bavarian Ministry of Food, Agriculture and Forestry, a multidisciplinary approach of different research institutes was conducted during a two-year research project. The aim of this work was to investigate the possibility of using a self-built and miniaturized NIR-sensor for the determination of tomato fruit maturity parameters such as sugar content, firmness and dry matter. A similar approach with focus on a commercially available pocket-sized NIR-sensor has already been performed (publication in review process). Based on these results, storage experiments were carried out in order to evaluate the feasibility of predicting shelf life of tomatoes with NIR-sensors. Tomato was chosen as model fruit because of its economic importance. An early determination of maturity as well as shelf life of tomatoes could help to control the supply chain and take alternative paths for produce not suitable for the fresh market (e. g., processing into soups, juices or smoothies). Furthermore, appropriate measures like sales promotions of ripe fruits can be launched in order to reduce food waste.

2 Material and methods

2.1 Sample material

Cherry- and salad-tomatoes (*Solanum lycopersicum* ′EZ 1359′ and ′EZ 1256′) from a greenhouse of the University of Applied Sciences Weihenstephan-Triesdorf (latitude 48°24′6″N and longitude 11°43′53″E) were used as sample material. Tomato plants were cultivated in a run-to-waste system on rock wool. Determination of sugar content, firmness, dry matter and color values of tomato fruits was done during the summer of 2017 at the Institute of Horticulture, Freising, Germany.

2.2 Methods and storage conditions

In a first experiments, 40 salad- and 40 cherry-tomatoes were harvested and the spectra recorded. Afterwards, sugar content in terms of TSS-concentration of each individual fruit was measured. In a second experiment, 120 tomatoes (60 cherry and 60 salad) were harvested and stored at room temperature (20 - 22 °C) for two weeks to evaluate post-ripening-processes with respect to changes in fruit skin color and dry matter. Every two days, spectra of ten fruits of each variety were taken and fresh weight, dry weight and color values of each fruit was recorded. In order to model shelf life and the decay of tomato fruit firmness over time, a third experiment was conducted using different storage conditions. 320 salad- and 360 cherry- tomatoes were harvested from the greenhouse. Spectra was recorded and firmness measured of 16 salad- and 20 cherry-tomatoes to determine initial fruit firmness. The remaining tomatoes were stored in batches of equal size under three different storage conditions at 8, 15 and 20 °C and relative humidity of 96 - 98 % respectively using laboratory refrigerators (Liebherr Mediline model LKPv 6522, Liebherr-International GmbH, Biberach, Germany). The resulting vapor pressure deficits were 2,1 - 4,3 hPa (8 °C), 3,4 - 6,8 hPa (15 °C) and 4,6 - 9,4 hPa (20°C). Every two to three days, the spectra of ten fruits of each variety and storage condition were recorded and firmness was measured. Due to moldiness and other physiological disorders during storage, 6 salad- and 11 cherry-tomatoes had to be excluded from the experiment, resulting in a valid data set of 314 salad- and 349 cherry-tomatoes.

2.3 Recording of NIR spectra

Spectroscopic measurements were performed using a self-built handheld NIR spectrometer consisting of a DLP® NIRscan™ Nano Evaluation Module (Texas Instruments, Dallas, Texas), supporting wavelengths from 900 - 1700 nm, embedded in a custom-built aluminum case (see Fig. 1A.). The method of measurement is diffuse reflection. Spectra of tomatoes were recorded by taking eight separate measurements orthogonally around the equator of each fruit (see 1.1) using a reprogrammed graphical user interface (GUI). The eight spectra for each fruit were averaged afterwards.

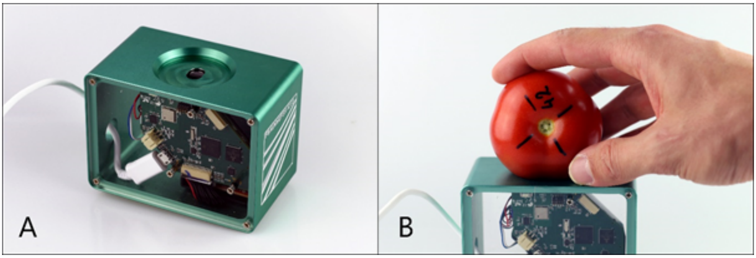

Figure 1.1: Custom-built hand held NIR spectrometer (A) and recording of tomato spectra around the fruit equator (B)

2.4 Acquisition of reference data

Reference measurements were performed immediately after recording spectra. Total soluble solids (TSS) were measured according to the OECD fruit and vegetable scheme by squeezing two longitudinal slices from opposite sides of the fruit with a garlic press and measuring the mixed juice with a digital refractometer HI 96801 (Hanna Instruments, Woonsocket, USA). The results, in degrees Brix, were recorded to one decimal place. The concentration of dry matter (DM) was measured gravimetrically for whole tomatoes. Weight of fresh fruits was determined to the nearest 0,001 g. Subsequently fruits were dried in an oven at 105 °C for 48 h. The final dry weight was determined to the nearest 0,001 g and DM calculated as the percentage of dry weight to initial fresh weight of each fruit. Firmness was measured using a non-invasive hand-held penetrometer AGROSTA 100X (Agro Technologie, Serqueux, France) specifically designed to measure tomatoes and berries. The penetrometer expresses firmness of fruits in a unit of percent in a range from 0 - 100, whereas 100 percent equals 8,09 Newton. Results were converted to Newton by taking account of penetrometer-pin-diameter and the maximum force used to push in the metal pin. Measurements were taken at two spots on opposite sides of the equator of each tomato. Both readings for each tomato were averaged. Additionally a subjective firmness bonitur was performed by the first author, grading tomatoes into the bonitur classes A (very firm), B (firm) and C (soft).

3 Results and discussion

The data analysis was performed with *Python* using the *scikit-learn* framework [13]. After a normalization in the first step, the regression models were developed to establish a relationship between the normalized spectra and the properties of salad and cherry tomatoes. To verify the models a *leave-one-out-cross-validation* (LOOCV) was performed.

3.1 Spectral preprocessing

To reduce scattering effects and noise, spectral preprocessing was applied. Because of the signal-to-noise ratio, the spectral range for the analysis was reduced to 198 bands between 901 nm and 1608 nm. For noise suppression, the mean value of all spectra of a sample was calculated and in addition, the mean value spectra were smoothed with a Savitzky-Golay filter (15,3). In a further step, the first derivative was formed to correct the baseline due to different scattering properties. Finally, different intensities were compensated by normalization using Standard Normal Variate (SNV).

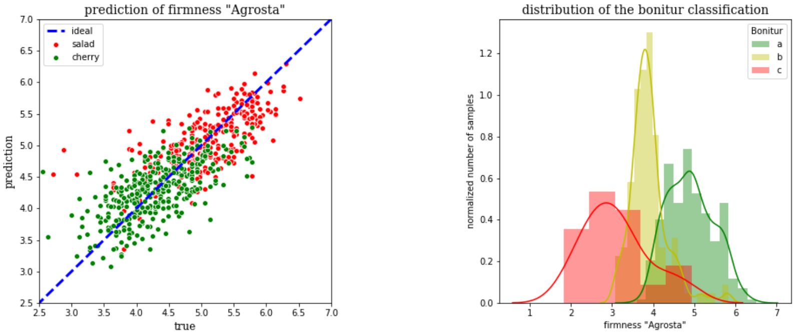

Figure 1.2: PLSR prediction of the dry matter using the normalized spectra. The multi-product model works well for both varieties. (RMESP ’salad’ = 0.45, RMESP ’cocktail’ =0.45). The bonitur classification is related to the firmness. Therefore, a clear dependence of the quality score on the measured firmness can be seen.

3.2 Prediction of quality attributes

The normalized spectra can be used to predict the firmness of the tomato by a partial least squares regression modell (PLSR) modell. A multi-product PLSR model was developed, which was trained with the spectra of both varieties. The root-mean-square-error-of-prediction (RMSEP) of the model determined in a cross validation is 0.52 for salad tomatoes and 0.5 for cherry tomatoes (see fig. 1.2).

There is also a relationship between the optically and mechanically measurable firmness and the quality evaluation of the bonitur (see fig. 1.2). This allows classification into three quality levels on the basis of the measurable firmness.

In addition to the firmness, which can be used as the main criterion for freshness and shelf life, further parameters were determined. First, the dry matter was evaluated. It should be noted that the correlation coefficient between strength and dry matter has a value of 0.77. In a multi-product calibration of 40 salad and 40 cherry tomatoes a PLSR model for the prediction of dry matter could be created. The RMSEP of the dry matter was 0.50 and 0.52, respectively, with the values of both varieties ranging between 5 % and 9 % dry matter.

To predict the brix value, a multi-product calibration for salad and cocktail tomatoes using PLSR was also made. The brix value of the tomatoes could be determined with an RMSEP of 0.56 and 0.68 °brix for salad and cocktail tomatoes in the range between 4 and 9 °brix .

3.3 Prediction of shelf life

In this regard, firmness can be used as one of the parameters to estimating shelf life of tomatoes. To this end, the time dependency over storage can be modeled by using the Arrhenius equations [14,15].

Data analysis is performed through the packet R software. The loss of firmness for all three-temperature levels as well as the final models for the three temperature levels are plotted in Figure 1.3. The kinetic parameters as well as the activation energy can then be extracted from the model. In Figure 1.3 the quality classes A, B and C are presented based on bonitur classifications. It shows that along the storage of tomatoes, the subjectively perceived firmness declines due to vapor pressure deficit and storage time. Since in this experiment, the vapore

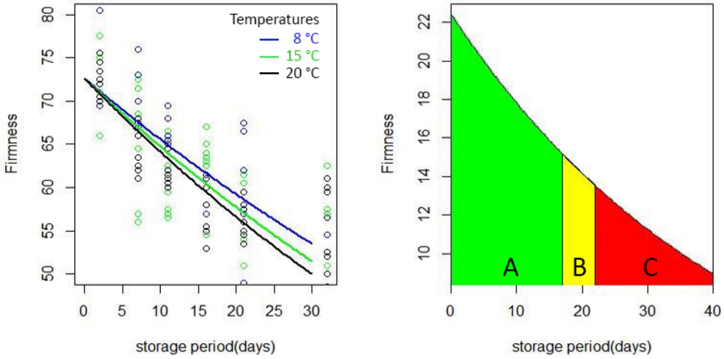

Figure 1.3: Firmness measured at 3 different temperature levels [8°,15°,20°C] and the fitted curves of the Arrhenius models (left). Firmness – storage time model for temperature 20°C indicating 3 different quality classes for salad tomatoes (right)

pressure deficit was relatively small, the influence of storage period is rated higher than the influence due to temperature. By considering the storage conditions at the point of sale with notably higher vapor pressure deficits (e. g. 50,2 hPa at 20°C and 50 % relative humidity) a faster decline in firmness can be expected.

4 Summary

Firmness is a strong parameter for quality of tomatoes. However, the measurement of firmness using classical measuring methods like penetrometers leads to fruit damage, manifesting itself in bruises and subsequently in a fast decay of the fruits. A similar practice can bee seen in supermarkets when consumers try to assess quality by touching the fruits. In both cases a non-destructive and non-contact optical measurement offers an advantage [16]. The results of this study show that firmness can be predicted with good accuracy using a miniaturized NIR-sensor. Furthermore, a relation between bonitur classifications and objective firmness measurements was established, indicating the possibility of distinguishing bonitur grades by means of NIR-spectroscopy. It is also shown that the decline of firmness over storage time with respect to vapor pressure deficit of tomatoes can be modelled. In combination, the decline of firmness as an indicator for shelf-life can be predicted using this portable NIR-Sensor.

Future work should address the validity of the PLSR correlation by adding new tomato varietes to the data set. Regarding the utilization of portable NIR-sensors by end-consumers these data sets should focus on varieties available in supermarkets.

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