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Non-destructive measurement method for a fast quality evaluation of fruit and vegetables by using food-scanner

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1. Introduction, Knowledge, Objectives

Recent reports estimate the volume of food loss along the supply chain to 1,3 billion tons globally per year, which equals one-third of food produced for human consumption (FAO, 2011). Further studies conducted for the german food supply chain estimate the quantity of annual food loss between 11 million (Universität Stuttgart, 2012) and 18 million (WWF, 2015) tons. Fruits and vegetables, with a percentage of 44 of the total food loss, are commodities most frequently thrown away (BMEL, 2012).

In recent years, a lot of attention is given to so-called food-scanners. Food-scanner are miniaturized near-infrared (NIR) spectrometers, which allow a fast and noninvasive determination of food quality. They can be used as a multidimensional predictor to determine the chemical and physical composition of agricultural- and food products (e.g. soluble solids, dry matter, moisture, firmness). Due to their small size and portability these devices can be used for in-field application as well as for researchers and end-consumers (Santos et al., 2013).

Studies of Flores et al. (2009) and Kim et al. (2013) indicate that NIRS is suitable for predicting quality attributes of various tomato varieties. The experiments described in this study are conducted on tomatoes and focus on the performance of a food-scanner compared to a benchtop NIR-spectrometer. Important quality parameters of tomato, such as sugar content and firmness, are evaluated with respect to their predictability in order to validate the performance of this new kind of non-destructive measurement-method.

2. Material and Methods

2.1 Materials

Salad- and cocktail-tomatoes (*Solanum lycopersicum* 'EZ 1256' and 'EZ 1359') were harvested in September and October 2017 from a greenhouse of the University of Applied Sciences Weihenstephan-Triesdorf (latitude 48°24'6''N and longitude 11°43'53''E), where they have been cultivated throughout the summer of 2017 in a run-to-waste system on rock wool. After removing the stems tomatoes were numbered with a waterproof marker at the stem basis. In a first experiment, 160 tomatoes (80 salad and 80 cocktail) were stored for three weeks to initiate post-ripening-processes and to obtain different quality levels in terms of sugar-concentration, which is expressed as total soluble solids (TSS). Ten fruits of each cultivar were then measured spectrometrically and destructively for TSS every two to three days. A second experiment was conducted with 120 tomatoes (60 salad and 60 cocktail) for the determination of firmness and dry matter (DM). Fruits were stored for two weeks to enable water loss of fruits and to obtain different levels of firmness and dry matter in tomatoes. Ten fruits of each variety were measured spectrometrically every two days followed by measurements for firmness and dry matter. Fruits in both experiments were stored at room temperature (20 °C at night - 22 °C at day) and relative humidity of 60 - 70 % under ambient light conditions at an average of 0,4 W/m² for 12h during the day.

2.2 Recording of spectra

Spectroscopic measurements were performed using a hand-held SCiO spectrometer version 1.2 (Consumer Physics, Tel Aviv, Israel) and a benchtop NIR spectrometer (Carl Zeiss MCS 621 VIS II with reflection measuring head OMK 500-H, Jena, Germany). The measurement method for both devices is diffuse reflection. Fruit spectra of tomatoes were recorded with the SCiO by taking four measurements orthogonally around the equator of each fruit (Figure 1A). For the benchtop device, spectra were acquired using a turntable (Figure 1B). Rotating fruits were scanned for six seconds. The 60 spectra recorded in this time were averaged using CORA Plus and OPC run software (Carl Zeiss, Jena, Germany).

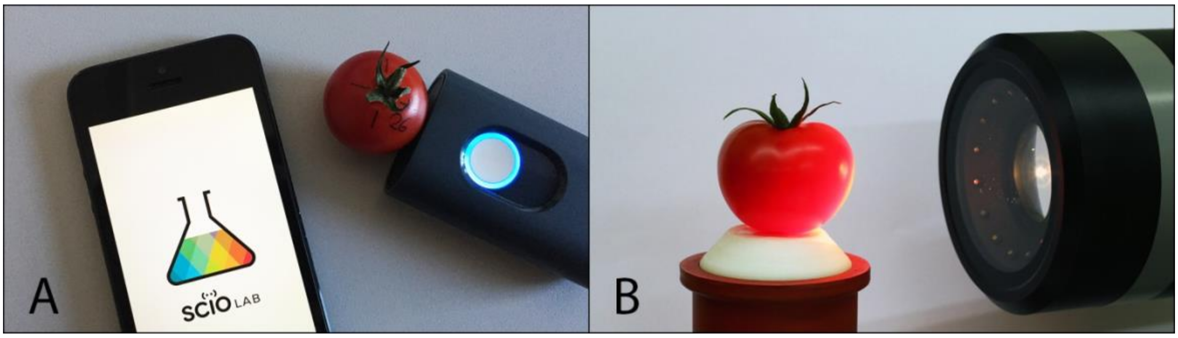

Figure 1. Recording of spectra using the portable food-scanner SCiO (A) and a Zeiss benchtop NIR-spectrometer (B)

2.3 Acquisition of reference values

Reference measurements were made directly after recording spectra. Firmness was measured by averaging four measurements around the equator of each fruit using a non-invasive hand-held penetrometer AGROSTA 100X (Agro Technologie, Serqueux, France). Measurements were taken at the spots where spectra were acquired with the SCiO. Values are expressed in Newton by taking account of penetrometer-head-diameter and maximum force. Since fruits were not damaged and no fruit tissue was lost by this penetrometer, tomatoes were subsequently used for TSS and DM measurements.

Sugar content in terms of TSS was analyzed according to the OECD fruit and vegetables scheme by taking two longitudinal slices from opposite sides of the fruit, squeezing the slices with a garlic press and measuring the mixed juice with a digital refractometer HI 96801 (Hanna Instruments, Woonsocket, USA) in degrees Brix to one decimal place. Dry matter was measured gravimetrically for whole tomatoes. Fresh fruits were weighed and then dried in an oven at 105 °C for 48 h. The final dry weight was used to calculate DM as the percentage of dry weight to initial wet weight of each fruit.

2.4 Statistical analysis / multivariate analysis

After acquiring reference values, every averaged firmness-, TSS- and DM-value was correlated with the four SCiO spectra and the averaged Zeiss spectrum, respectively. Partial least square (PLS) models were developed with the open source statistical software R and Unscrambler (CAMO, Oslo, Norway) to establish prediction models for TSS, firmness and DM values. Sample data contains a combination of both tomato varieties (salad and cocktail) in order to generate a wider range of values. Data was preprocessed by taking the second derivative of the spectra and applying a standard normal variate correction (SNV), which led to the best result for the prediction models. The Savitzky-Golay transformation was performed with a filter width of 25. For analysis of TSS eight batches with 20 samples resulted in a total sample size of 160. Data of 120 samples, comprising six batches with 20 samples, was used for establishing models for dry matter and firmness. Cross validation for each analysis was carried out with a sample of 20 segments

3. Results

In this study, the SCiO device delivered prediction models with high linear correlations (r^2), ranging from 0.80 for dry matter, 0.82 for firmness to 0.92 for TSS. In comparison, models for the Zeiss-spectrometer showed higher values for linear correlations for every parameter examined (0.94 for TSS, 0.83 for firmness and 0,85 for dry matter). The errors of prediction, expressed as root mean square errors (RMSE), for TSS and dry matter were lower for the benchtop-device compared to the SCiO (0.37 °Brix instead of 0.45 °Brix for TSS and 0.38 % DM instead of 0.41 % DM). Firmness showed similar prediction errors (0.57 N) for both devices. Performance of models for all three traits examined in comparison to the respective spectrometer is shown in Table 1.

Table 1. Comparison of performance of SCiO handheld- and Zeiss benchtop-spectrometer for prediction of TSS, firmness and dry matter

Quality parameters	**λ**	**n**	**r^2**	**RMSE**
SCiO Handheld Device	740 - 1070 nm Resolution: 1 nm			
TSS (Brix)		160	0.917	0.453
Firmness		120	0.815	0.566
Dry Matter		120	0.802	0.412
Carl Zeiss MCS 621 VIS II	750 - 1080 nm Resolution: 2 nm			
TSS (Brix)		160	0.939	0.368
Firmness		120	0.829	0.570
Dry Matter		120	0.846	0.383

Figure 2 shows exemplarily the correlation between dry matter measured during the experiment and the obtained spectra. After calibration (red values) the model presented a

RMSE of 0.30 % DM and a linear correlation (r^2) of 0.89. Using this model and applying a second dataset (blue values) for validation, the model shows a RMSE of 0.41 % DM and a correlation of 0.80.

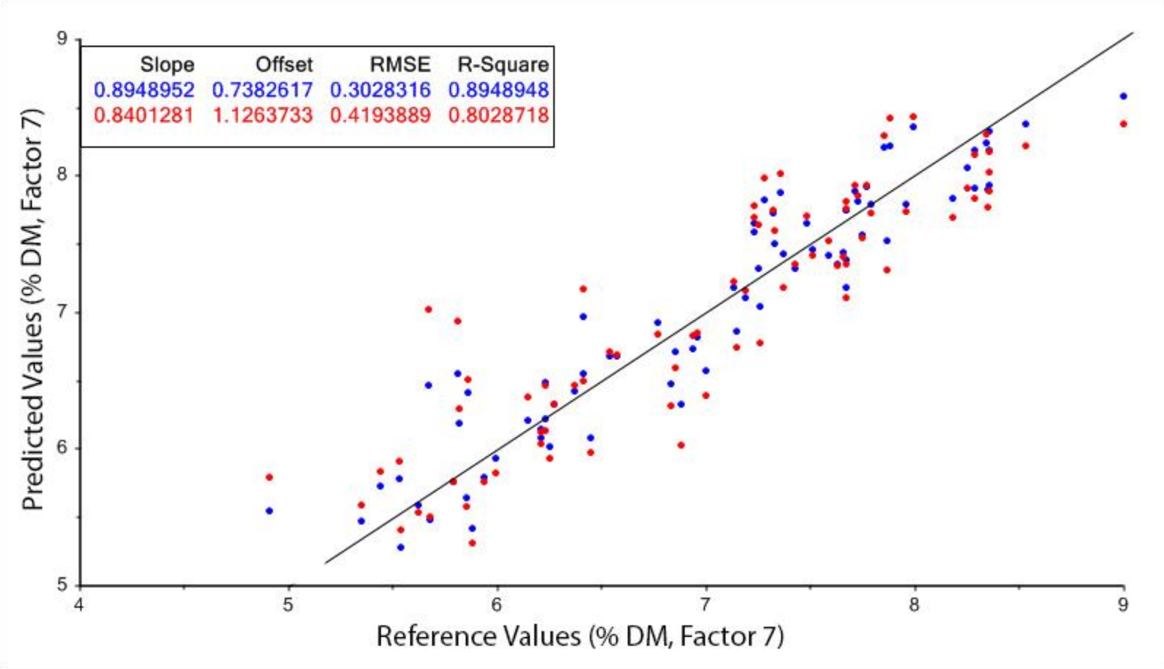

Figure 2: Accuracy of prediction of tomato dry matter using the SCiO device. Blue values were used for calibration, red values for validation of the model

4. Discussion

Main purpose of the developed PLS models was the performance-evaluation of the handheld device SCiO and the comparison to a benchtop-spectrometer. The results of both devices show that the examined quality parameters (TSS, DM, firmness) had a high correlation to collected spectra. For the SCiO device these predictions showed a slightly lower r^2 and some higher RMSE values compared to the Zeiss spectrometer. Nevertheless the obtained results indicate that the SCiO could be used for the prediction of firmness, dry matter and TSS with good to high accuracy. Similar experiments for the SCiO have only been performed with apple and kiwi (Kaur et al., 2017) and showed comparable results for the predictability of dry matter ($r^2 = 0.87$, RMSEP = 0.70 % DM). PLS regression performed by Kusumiyati et al. (2008) for a portable NIR spectrometer resulted in a slightly higher $r^2 = 0{,}89$ for the prediction of tomato firmness after harvest.

The models built in this study are based on two tomato varieties grown locally at the University of Applied Sciences. To be able to make accurate predictions in a more general way, e.g. by building a global model for the prediction of TSS, DM and firmness, additional tomato varieties need to be included into the existing data. Adding samples from the supermarket could also help to improve these global models by displaying quality further down the supply chain.

Additional preprocessing of data (focus on different spectral ranges, improvement of signal to noise ratio) could lead to optimization of prediction models and will be part of further studies.

5. Conclusions

First results obtained for tomatoes show promising possibilities for a prediction of fruit quality in a non-destructive way. Since more quality parameters are necessary to give a precise prediction of the degree of ripeness and maturity, additional fruit parameters (e.g. color, moisture, content of lycopene) will be included in future studies. Furthermore, other hand-held devices need to be tested to take the effect of different wavelength-ranges into account. In the future, these devices could be used to determine fruit quality on different levels of the horticultural supply chain. Supporting decisions how to proceed with different batches of fruits, food-scanner can help to reduce food loss along the supply chain

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6. Literature

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