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NON-DESTRUCTIVE ASSESSMENT OF STRAWBERRY FRUIT QUALITY

Stefka ATANASSOVA[1], Mima TODOROVA[2], Stanislava ATANASSOVA[2], Dimitar YORGOV[1], Vania SKILA[3], Petya VELEVA[1], Galina PEVICHAROVA[4]

[1]Trakia University, Faculty of Agriculture, Department of Agricultural Engineering, 6015, Stara Zagora, Bulgaria
[2]Trakia University, Faculty of Agriculture, Department of Plant Production, 6015, Stara Zagora, Bulgaria
[3]Trakia University, Faculty of Agriculture, 6015, Stara Zagora, Bulgaria
[4]Maritsa Vegetable Crops Research Institute, 32 Brezovsko shosse St, Plovdiv, Bulgaria

Corresponding author email: mima.todorova@trakia-uni.bg

Abstract

Conventional methods for fruit analysis are often destructive, time-consuming, and labor-intensive. Rapidly and non-destructively detecting fruit quality is an important topic in fruit agriculture. The aim of the research is a non-destructive assessment of the quality of strawberry fruits of three varieties grown in a greenhouse. A total 90 number of fruits were collected, 30 of each variety. The diffuse reflectance spectral data of all fruits in the region 900 to 1700 nm were obtained using NIRQuest (Ocean Optics, Inc.). The soluble solids content (°Brix), ascorbic acid, and texture parameters (rupture force, yield force, modulus of fresh elasticity, and deformation work) were measured on each fruit. PLS regression was used to create models for the determination of tested parameters. Good PLS equations were obtained for soluble solids content and ascorbic acid content. The parameter RPD = SD/SECV, which is used to evaluate the accuracy of the determination, has values of 3.06 for SCC and 4.57 for ascorbic acid content. The accuracy of defining textural parameters was excellent. For each of them, the correlation coefficient R_{cv} was 0.99 and the determination errors were small. No difference was observed in the accuracy of the determination of tested parameters depending on the strawberry varieties.

Key words: *strawberry, soluble solids content, ascorbic acids, texture, NIR spectroscopy, PLS Regression.*

INTRODUCTION

Strawberries are one of the popular high-value fruits with numerous nutrients and health benefits. They are a rich source of vitamins, polyphenols dietary fiber, and minerals (Giampieri et al., 2012). Recent clinical studies have confirmed that strawberries can reduce the serum levels of the branched-chain amino acids valine and leucine as well as significant increases in untargeted metabolites, including serum phosphate, benzoic acid, and hydroxyphenyl propionic acid (Basu et al., 2023). The authors concluded that dietary supplementation of strawberries significantly improves the serum metabolic profiles of cardiometabolic health of adults.

Conventionally, strawberry quality has been evaluated with criteria such as color, texture, chemical constituents, etc., by fruit experts or researchers (Rico et al., 2007; Temocico et al., 2019). These methods are often destructive, time-consuming, and labor-intensive. Also, destructive methods cannot be applied to the entire batch of a product, but only to a certain number of fruits. Nowadays people's requirements in terms of food quality are increasing. Non-destructive testing methods and chemical-free analytical procedures are needed for farmers, in the supply chain of fresh strawberries or the process industry.

In recent years, with the development of near-infrared (NIR) spectroscopy and advanced optical imaging techniques such as multispectral and hyperspectral imaging in visible and NIR regions, a rapid increase use of these instruments can be seen in assessing the chemical composition and quality of fruits in a non-destructive way (Alander et al., 2013; Chandrasekaran et al., 2019; Aline et al, 2023; Guo et al., 2024). The development of spectrometers and the current availability of portable devices allow analysis not only in the laboratory but also in the field, which is of particular importance for determining the maturity and quality of fruits and the most suitable moment for harvesting them.

Recent studies, related to the assessment of the sensory and nutritional quality of strawberries using visible and near-infrared spectroscopy have been published. The most tested parameters are soluble solid content, acidity, and firmness. Shao and He, 2008 reported a successful prediction model for acidity in strawberries based on wavelet transform combined with partial least squares (PLS) with a correlation coefficient of 0.856 and root mean square error of prediction (RMSEP) of 0.026. Sánchez et al., 2012 using a MEMS handheld instrument analyzed five commercial cultivars of strawberry. The authors reported the feasibility of NIRS for the prediction of firmness, soluble solid content, and titratable acidity. Amodio et al., 2017 investigated the potentiality of NIR spectroscopy to predict the internal quality attributes of organic and conventionally grown strawberries. The authors reported good prediction models for soluble solid content, pH, and total acidity. The other parameters - ascorbic acid and phenols, were predicted with much lower accuracy. Mancini et al., 2020 investigated the application of NIR spectroscopy for the prediction of soluble solid content, titratable acidity, firmness, and color of fresh strawberries. Good PLS models were obtained only for firmness and total soluble solids parameters. Another study of the same group (Mancini et al., 2023) proposes partial least squares discriminant analysis to classify four selected strawberry genotypes according to the quality parameters of soluble solids, vitamin C, anthocyanins, and phenolic acids contents. Saad et al., 2022 evaluated the potential of a hand-held Vis-NIR spectrometer to classify the maturity stage and to predict the quality attributes of strawberries. The developed models for the determination of colour parameters, total soluble solids, titratable acidity, and total polyphenol content had a coefficient of determination bigger than 0.9.

Hyperspectral imaging in the NIR range has been found useful for nondestructive estimation of the quality of strawberries. Tallada et al., 2006 reported that NIR hyperspectral images (650 to 1000 nm) and three-wavelength model (685, 865, and 985 nm) could predict firmness in strawberries. Hyperspectral imaging in the visible and near-infrared (400–1000 nm) regions was tested for nondestructive determination of moisture content, total soluble solids (considered a very important parameter in evaluation of the quality), and acidity in strawberries (ElMasry et al., 2007; Chen et al., 2018). The correlation coefficients bigger than 0.80 were reported for the prediction of tested parameters. A higher classification accuracy of 89.61% was achieved for classifying strawberries based on the ripeness stage. A hyperspectral imaging system covering two spectral ranges (380-1030 nm and 874-1734 nm) was applied by Zhang et al., 2016 to evaluate strawberry ripeness. The obtained classification accuracy was over 85%. An approach to visualize the spatial distribution of sugar content in white strawberry fruit flesh using near-infrared hyperspectral imaging in the region 913-2166 nm was developed by Seki et al., 2023.

The main objective of this study is to evaluate the capabilities of NIR spectroscopy for the nondestructive determination of quality and textile parameters of fresh strawberries from three varieties grown in a greenhouse.

MATERIALS AND METHODS

Strawberry samples

Strawberries belonging to three commercial cultivars - Asia, Alba, and Clery were used in this study (Figure 1). The strawberries were grown in a greenhouse of Trakia University academic technological complex, under irrigated conditions with drip irrigation. A total 90 number of fruits were collected, 30 of each variety. The Alba variety is created by crossing two varieties Albion and Cal. 97.85-6 from the Italian company New Fruits. The variety is characterized by conical, very uniform, bright red, and shiny fruits. The quality of the fruit is good and very stable. Variety Asia is an industrial variety of large and juicy fruits, first grown in Italy in 2005. Medium early variety that ripens 5 to 6 days later than Alba. The fruits are attractive, large, conical, very uniform, and extremely bright red.

a)

b)

c)

Figure 1. Investigated strawberry cultivars:
Alba (a), Asia (b), and Clery (c)

The variety is characterized by high sugar content and the balanced acid ratio, the taste is delicious. The fruits of Clery variety have a regular conical shape, uniform. The color of the berries is dark red saturated with shine. The taste is sweet with a characteristic sourness.
In order to determine the quality parameters, the fruits were harvested at different maturity stages (half-ripe and ripe stage) to enlarge the interval of variation of tested parameters in the calibration models.

Measurement of quality parameters
Analysis of the mechanical characters and chemical compounds of the fruits was performed at the Laboratory for Vegetable Quality Control of Maritsa Vegetable Crops Research Institute - Plovdiv. Textural parameters were studied on the day of the harvest. The laboratory tests were conducted by TA.XT.Plus Texture analyser (Stable Micro Systems, UK) equipped with a Heavy Duty Platform (HDP/90) with holed plate and a 2 mm diameter stainless steel puncture probe (SMS P/2). The instrument was set at a test speed of 2 mm s^{-1} and a travel distance of 10 mm. The analysis was performed on individual fruits of investigated cultivars. The measurement was done in the equatorial part of the longitudinal slices. The force-deformation curves were analysed for yield force (1st force maximum), modulus of flesh elasticity (slope up to 2nd maximum), deformation work (area under the curve up to 2nd maximum), and rupture force (force maximum) (Figure 2).

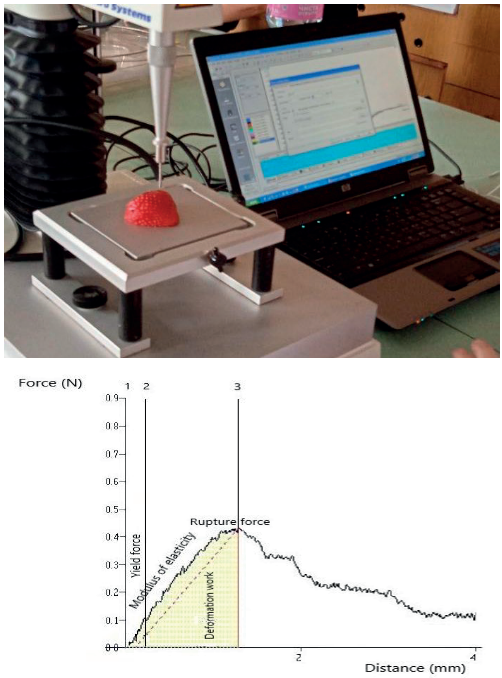

Figure 2. Stable Micro Systems TA.XT. Texture Analyser and typical force-distance curve of the fresh strawberries

Each strawberry fruit was analysed for soluble solids content (SSC) using a digital refractometer and ascorbic acid by Tilman's reaction with 2, 6-dichlorophenolindophenol (Genadiev et al. 1969).

Spectral measurements

NIRQuest 512 (Ocean Optics, Inc.) spectrometer in the range 900-1700 nm and optical resolution 3.1 nm. Spectral acquisition of tested 90 strawberry fruits was made using a reflection fiber-optics probe. The instrument was set to average 20 scans for one spectrum. The fruits were measured at three positions along its equator approximately spin 120 degrees.

The spectral data processing was performed with Pirouette 4.5 software (Infometrix, Inc.). PLS models were used for development models for quantitative determination of tested parameters with cross-validation. The optimum number of PLS factors in each model was defined to be the one that corresponded to the lowest standard error of cross-validation (SECV). Different mathematical treatments were evaluated - smoothing, multiple scatter correction, first and second derivative.

RESULTS AND DISCUSSIONS

Differences in measured parameters between strawberry varieties were found. The mean value of SSC was higher for the Clery variety – 8.80 and lower for the Asia variety – 6.89. Ascorbic acid content was higher for fruits from the Alba variety. Among textural parameters, the main differences were found for the modulus of flesh elasticity.

The range, mean values, and standard deviation for the total group of samples from three strawberry varieties for each measured quality parameter are reported in Table 1. A relatively high range of measured parameters' values was observed because fruits from different varieties were included in the data set.

The average absorbance spectra of the three tested strawberry varieties are presented in Figure 3. The spectra of the three cultivars were very similar with small differences among them. The absorption maxima were observed around 930, 990, 1190, and 1410-1470 nm. The biggest maxima in the region 1410-1470 nm might be assigned mainly to O–H vibration from water and sugars. The absorption at wavelength regions around 930 and 1190 nm might be related to C–H vibrations, and at 980 nm to O–H vibrations (Workman &. Weyer, 2008). Similar spectral characteristics of strawberries were reported by Seki et al., 2023.

Table 1. Quality attributes of strawberry fruits.

Parameters	Range	Average	SD*
Soluble solids content, ^{0}Brix	4.6-12.1	8.39	1.85
Ascorbic acid, mg %	51.60-81.27	65.45	7.99
Yield force. N	0.241-0.765	0.429	0.148
Rupture force, N	0.384-1.185	0.682	0.229
Modulus of flesh elasticity, N.mm^{-1}	0.017-1.045	0.351	0.225
Deformation work, N.mm	0.080-0.905	0.339	0.229

*SD – standard deviation

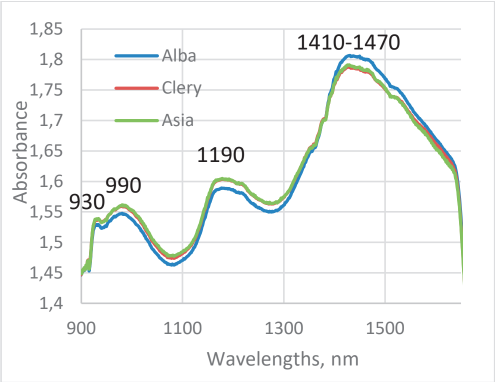

Figure 3. The average absorbance spectra of the tested strawberry varieties

Table 2 shows statistics for the best equations for the prediction of internal quality and textural parameters of the fruits based on the strawberries' near-infrared spectra. For most of the study parameters, slightly better results were obtained using the first derivative transformation of the spectral data. Mancini et al., 2020 also found the best PLS model for the determination of SSC using the first derivative transformation of strawberries' spectral data. The exception was only for the ascorbic acid content, which best equation was obtained by transforming the spectra as a second derivative. Between 5 and 8 PLS components were used in the regression equations.

Table 2. Calibration statistics for internal quality and textural parameters in strawberries using PLS regression

Parameter	SECV	R_{CV}	SEC	R_{Cal}
Soluble solids content, ^{0}Brix	0.605	0.93	0.569	0.94
Ascorbic acid, mg %	1.75	0.95	0.11	0.99
Yield force. N	0.007	0.99	0.004	0.99
Rupture force. N	0.016	0.99	0.008	0.99
Modulus of flesh elasticity. $N.mm^{-1}$	0.017	0.99	0.009	0.99
Deformation work. N.mm	0.004	0.99	0.002	0.99

SECV - standard error of cross-validation, R_{CV} - cross-validation correlation coefficient. SEC, Standard error of calibration, R_{cal} - coefficient of multiple correlation,

A graphical illustration of the accuracy of NIR spectroscopy prediction of tested parameters was presented in Figure 4 for ascorbic acid content, Figure 5 for soluble solids content, and Figure 6 for rupture force, respectively.

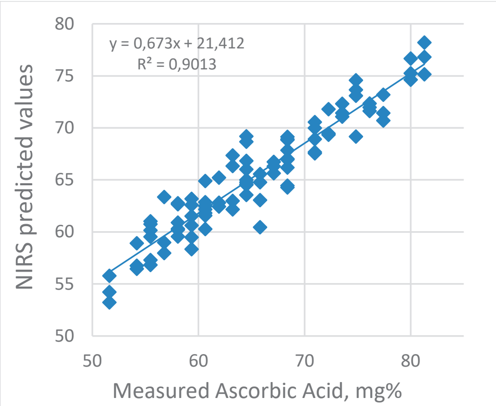

Figure 4. Regression plot of the Partial Least Squares Regression (PLS) model for predicting ascorbic acid content (cross-validation results)

Good PLS equations were obtained for SSC and ascorbic acid content. The parameter RPD=SD/SECV, which is used to evaluate the accuracy of the determination, has values of 3.06 for SCC and 4.57 for ascorbic acid content. RPD values greater than 3 indicate very good determination accuracy. No difference in the accuracy of determination of these parameters depending on the studied varieties was observed.

Similar results for the prediction of SSC and vitamin C were reported by Weng et al, 2000, based on VIR/NIR spectra (400-1000 nm) of strawberries at different ripeness stages.

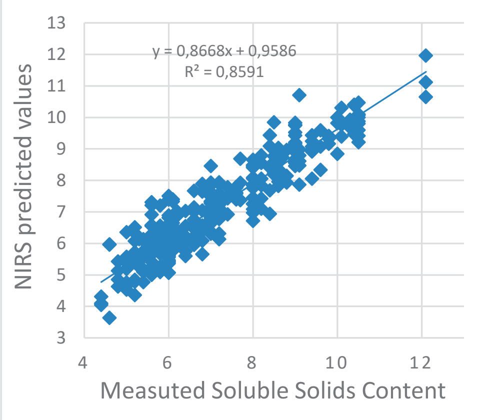

Figure 5. Regression plot of the Partial Least Squares Regression (PLS) model for predicting soluble solids content (cross-validation results)

The accuracy of defining textural parameters was excellent. For each of them, the correlation coefficient R_{cv} was 0.99 and the determination errors were small, as can be seen for example in Figure 6.

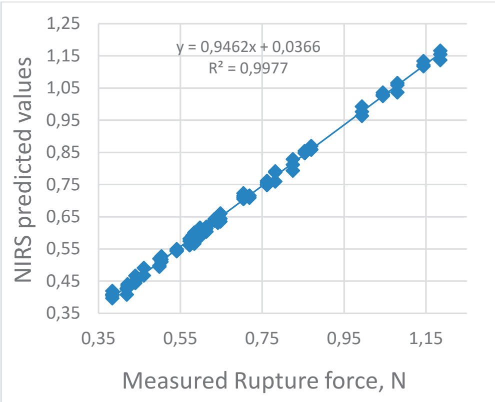

Figure 6. Regression plot of the Partial Least Squares Regression (PLS) model for the prediction of rupture force (cross-validation results)

CONCLUSIONS

The results show the potential of near-infrared spectroscopy for predicting the SSC, ascorbic acid and textural parameters of strawberries non-destructively from the fruit spectra.

Near Infrared Spectroscopy (NIRS) can be an alternative to the destructive methods for analysis of soluble solids content, ascorbic acid, and texture of strawberries.

Nowadays, some NIR spectrometers are portable and can be used outside the laboratory, in the field, to simultaneously evaluate the ideal harvest stage, and storage time, or to the development of fruit sorting systems to optimize their use.

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