SZENT ISTVÁN University

Examination of plant characteristics important Solanaceous vegetable crops (tomato, eggplant, paprika) plant characteristics by spectroscopic methods

Thesis of PhD Dissertation

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GÖDÖLLŐ

2017

Doctoral School

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1 INTRODUCTION

1.1 Scientific importance and background

Vegetable crops of the family *Solanaceae* family, tomato (*Solanum lycopersicum* L.), eggplant (*Solanum melongena* L.) and paprika (*Capsicum annuum* L.) are of great popularity worldwide. Tomatoes were the most significant (163 million tonnes), but the yield of eggplant (50 million tonnes) and paprika (31 million tonnes) was also significant in the world in 2013. In the case of tomatoes, roughly one quarter (40 million tonnes) of production is for processing. For eggplant and paprika this quantity is lower. In Hungary, after the bottom line of the tomato processing growing in 2012, a positive change began, one of which is a significant increase in the production area and at the same time an improvement in the intensity of cultivation. Eggplant production also shows an upward trend in Hungary. Paprika is the most consumed vegetable in both raw and processed form, in the latter case the importance of the kápia type is increasing.

Aerial and field hyperspectral spectroscopy, which has been used in vegetation research, has become increasingly important in precision plant production, regarding horticultural crops. For this, it was necessary to develop spectrometers, which became smaller and lighter, so they can be mounted on drones. The scope of rapid-spectroscopic testing is quite wide, as it can be mobilized, it takes a considerably shorter time, cheaper than analytical laboratory testing and non-destructive. Significant progress has been made in the last few decades in the spectroscopic analysis of agricultural products, food raw materials and end products.

Different phenological stages of different plant species or of one species also have different morphological (cell wall thickness, intercellular space and wax layers) and biochemical (water, pigment and carbohydrate content) characteristics. This is also reflected in their different spectral properties, which can be used for categorizing or classifying in agriculture or forestry. The six-decade irrigation experiment in the Institute of Horticulture, was complemented with non-destructive canopy temperature measurements three decades ago. As a continuation of this, in 2011 measurements were started with portable, visible and near-infrared (VIS/NIR) spectrometer devices. The tests were carried out under field and laboratory conditions.

1.2 Objectives

The aim of the studies was to determine the effects of abiotic factors (water and light supply) on the reflective properties of leaves and fruits of vegetable species grown in the open field (tomato, eggplant and paprika).

• The effect of irrigation treatments on the yields of processing tomato, especially its soluble solids content.
• Determination of the spectroscopic characteristics of processing tomatoes, eggplant and kapia paprika leaves by FieldSpec HandHeld 2 ™ Portable spectroradiometer.
• Determining the impact of irrigation and water scarcity stress on the spectral properties of the processing tomato leaves.
• Determining the effect of irrigation on the spectral properties of eggplant leaves.
• Determination of shading ability of different coloured nets, and the quantitative and qualitative yield parameters of the kapia paprika crops under them.
• Determining the effect of irrigation and water scarcity stress on the most important parameters and spectral characteristics of tomato fruits.
• Development of calibration models for the estimation of soluble solids, lycopene and total polyphenol content of processing tomatoes, from VIS/NIR (325-1075 nm) reflectance of homogenised fruits.

2 MATERIALS AND METHODS

For the objectives, I have carried out open field experiments in Gödöllő, at the Szent István University's Experimental Farm of Horticulture, between 2012-2015. The processing tomato has been examined in all four years, while only the data for 2013 have been processed from the measurements of eggplant and kapia paprika (under different coloured shading nets). I have only investigated hybrids from the processing tomato (Uno Rosso F1, Heinz 9663 F1, Triple Red F1, UG Red F1, Strombolino F1), eggplant (Barcelona F1) and kapia paprika (Karpia F1, Karpex F1). The mature fruits of processing tomato were analysed for analytical measurements in 2012. Plant propagation and cultivation technology has been carried out in accordance with many years of practice.

In the irrigation treatments, 100% of the optimal (I_d) irrigation demand, 50% of the irrigation and control plants were compared. The irrigation water doses corresponding to the daily water requirement of the 100% irrigation treated plants were replenished three times per week and, by analogy, I calculated the irrigation water dose of the 50% stocks using the following equation:

$$I_{d\,(mm)} = ((\mathrm{Tmax}(°\mathrm{C}) + \mathrm{Tmin}\,(°\mathrm{C}))/2)\mathrm{x}0{,}2(\mathrm{mm}/°\mathrm{C})$$

I_d: daily water demand (mm), Tmax: daily maximum temperature (°C), Tmin: daily minimum temperature (°C).

We used the ASD FieldSpec Handheld 2 Portable Spectroradiometer to measure the leaf reflectance measurements from early July 2013, continuously weekly, with 2-4 repetitions. In this way, 120 processing tomato, 104 eggplant and 240 kapia paprika reflectance spectra were recorded in the 325-1075 nm range.

The absorbance (A) of the coloured screening nets was calculated from the reflectance (R) of the white disk (USP 1119) used as the calibration reference, (A = log (1 / R), measured in the given plastic net compared to the non-shaded reflectance values.

For measuring mature processing tomato fruits, five red ripened berries in were homogenised in each four replicates, then subjected to spectroscopic and analytical testing. Examinations of nutritional values were carried out at the Food Chemistry and Analytical Department of the National Institute of Food Safety and Nutrition and in the Food Analytical Laboratory of the Central Food Research Institute, and from 2014, in the Food Analytical Laboratory of the Szent István University Regional Knowledge Centre.

3 RESULTS

3.1 Effect of irrigation on yield parameters of processing tomato between 2012-'15

Seasonal effects were different during experiments in processing tomato crops between 2012 and 2015. An important economic indicator connecting producers and processors is the Brix yield calculated from the average yields and the soluble solids content (°Brix) of the fruits. Although fruits harvested from irrigated crops each year were more dilute (R^2=0.70), the higher yields (R^2=0.72) due to irrigation and generally better plant condition compensated for this.

3.2 Leaf spectral characteristics of the investigated crops

I could distinguish between the raw reflectance of leaves in the VIS-NIR range (325-1075 nm) of the three investigated crops (tomato, eggplant, kapia paprika) in my thesis work, without the use of significant spectral resolution and pre-processing discriminatory methods.

3.3 Effect of irrigation and drought stress on leaf spectral characteristics of processing tomato

There are no differences in certain sections of the near infrared range, however, differences in the wavelengths from 900 nm to 1000 nm, irrespective of the varieties, but differentiating the irrigation treatments were observed. The best correlations of water supply and spectral reflectance were obtained by narrowing spectrum data to a range of 900-1000 nm and using the first derivative of the pre-processing algorithms. The model calculated by the software was suitable for separating the three-different water supplied crops, and the p-values for the estimation accuracy were 0.0032, 0.0028, 0.008, 0.0011 and 0.0008 in the order of consecutive measurements. The usability of the model was verified by cross validation. The water supply of plants was assigned to three values: -1.0 (K), 0 (50) and 1.0 (100), while the error limit was 0.5. In this way, from the treatment 100 estimates 8, from the 50 treatment estimates 5 and from the control were 9 values were outside the error limit. So, the model gave the least accurate results in control crops.

3.4 Effect of irrigation on leaf spectral characteristics of eggplant

The vegetative indices for the evaluation of the different water-supplying eggplants, NDVI (Normalized Difference Vegetation Index), PRI (Photochemical Reflectance Index), WI (Water Index) and ECI1 (Effective Chlorophyll Indicator) were used. These are dimensionless values spectral reflectance of leaves. Examining the relationship between the vegetation indices and

the irrigation only between the PR index and the water supply a correlation could be established, which can be characterized with a second-degree polynomial function:
($y=-0.00004x^2+0.0027x-0,0013$, $R^2=0,52$, $n=22$).

3.5 Effect of different coloured nets on the leaf reflectance of the kapia paprika crops

Differences in the infrared range were found between the reflectance values of paprika hybrids grown under different coloured shading nets. For Karpia F1 paprika, the highest reflectance was measured in the control, followed by the leaf values under white, yellow, green, pink and red nets. The reflection values of the Karpex F1 leaf differed in the order, decreasing values under white, yellow, pink, red and green colour nets. The modifier effect of the different colour shades on the leaf reflectance, with the results of the experiment, was first published from Hungary.

3.6 Effect of shading ability of different coloured nets

The absorption maxima typical of the nets revealed, that the red net had the biggest absorbance (0.295, 460-570 nm) in the full wavelength range (325-1075 nm). In the case of the green net, the absorbance was also above 0.2 at 400 and 650 nm. Based on this, it could be said that the most commonly used green net in Hungarian practice is the worst choice among the tested materials. The shading capacity of other three nets did not achieve the promised absorbance value even in the PAR region.

3.7 Effect of different coloured nets on the quantitative and qualitative yield parameters of the kapia paprika crops

The different colour shading nets had a different effect on the quantity and quality of harvested fruits of the covered crops. By examining Karpex F1 separately, the control treatment produced the least number of marketable and most sunburned fruits. In this respect, the order based on the yield surplus is: white (101.6%), green (118.4%), red (129.4%), pink (131.8%) and yellow net (158.2%). For the Karpex F1 hybrid, the effect of white and for the Karpia F1 the effect of green net caused the lowesr results in average yield. There were no sunburned fruits under the red and green nets. In the category of healthy fruits, crop yields under the yellow screening net were more than double compared to the control.

3.8 Effect of irrigation and drought stress on ingredients of processing tomato fruits

The reflectance of the homogenised tomato fruits also showed a difference in raw format and therefore seemed to be suitable for calculating a model for estimating soluble solids, lycopene and polyphenol content. During the modelling, I used the algorithm of the Partial Least Square Regression (PLSR) method, after the calculation of the first derivative and the use of the Savitzky-Golay filter. Selection of the most reliable model was based on the correlation coefficient of the cross-validation (R^2) and the Root Mean Square Error of Cross Validation (RMSECV). The error of cross-validation for soluble solids content was, 6.6% (R^2=0.77, RMSECV=0.51 ° Brix), 7.6% for lycopene (R^2=0.75, RMSECV=1.99 mg/100g) and 10.0% for total polyphenols (R^2=0.72, RMSECV=7.63 mg/100g). I also performed cross-validation verification graphically, showing the values calculated by the model in relation to the original data. Based on this, the soluble solids content model seemed to be suitable for estimation at a 4-6 °Brix interval.

3.9 New Scientific Results

1. Available water as precipitation or irrigation has significant positive (R^2=0.72) and negative (R^2=0.70) effect on yield and the soluble solids content of the tomato fruits in order.
2. I could distinguish the three investigated crops (tomato, eggplant, paprika) of my thesis work, by the raw reflectance spectra recorded in the VIS-NIR range (325-1075 nm) without the use of significant spectral resolution and preprocessing procedure.
3. During the examination of the leaf reflectance of the processing tomato hybrids, I could detect differences between the various water-supplied crops and between the hybrids, which were suitable for discrimination in the near infrared range, and I was able to model water supply regardless of hybrids and treatments.
4. During the examination of leaf reflectance in eggplant, I could detect discriminations for the different water supplied crops and the calculated PRI (Photochemical Reflectance Index) was closely related (R^2=0.53; n=22) with the amount of irrigation water applied prior to the measurement period.
5. The effect of the colour shading nets for paprika on the shading and reflectance of the leaves was first investigated in Hungary. I found differences that were discriminatory for treatments, in the near infrared range (750-1000 nm).

6. To measure the absorbance values of the photoselective nets, measurements using FieldSpec HandHeld 2 ™ Portable spectroradiometer showed that nets have significant differences in absorption.
7. The absorption peak of the most commonly used green net in Hungarian production coincides with the maximum absorbance of paprika leaves which, in addition to protecting against the scorching effects of harmful sun rays, can greatly reduce the productivity of the paprika growing under it.
8. From the studied different coloured plastic nets, paprika crops grown under the yellow net yielded the most marketable fruits.
9. From the reflectance values measured on homogenised fruits of processing tomato, I could distinguish between the various hybrids and the different water supply treatments in the visible and near infrared ranges. Information from the spectral results of the homogenised fruits of processing tomatoes showed a discriminatory drawing for irrigation water supplies.
10. The calibration model from the homogenised fruits of processing tomato hybrids is suitable for estimating the soluble solids at the 4-7 °Brix interval in the reflectance spectrum of the 550-975 nm range.

4 CONCLUSIONS AND RECOMMENDATIONS

Based on the temperature and precipitation conditions, the examined years were different. Except for the year 2014, good yields of processing tomato could only be achieved with irrigation. This is underlined by the results of previous studies, which indicate that in the three quarters of the years it is necessary to irrigate for proper yield. Although irrigation in addition to diluting tomato fruits and thus lowering the soluble solids content of the individual fruit, is compensated by a significantly higher yield, which is realized in higher dry matter yields.

Aerial and field hyperspectral spectroscopy, which has been used in vegetation research since then, has become increasingly important in precision crop production. The smaller and lighter spectrometers can even be mounted on drones. The leaves of different plant species (tomato, eggplant, and paprika) have different spectral properties, which can be used to create or classify categories.

Examination of processing tomato demonstrated that visible and near-infrared spectroscopy can be used with leaf reflectance data to determine the water supply regardless of the type and the phenological stage. Lower reflectance values are characteristic of better water supplied plants, while leaves of plants experiencing more or less water scarcity and therefore exposed to higher stress can be characterized by higher reflectance values. However, compiling a data series based on a larger number of spectral recordings is necessary to make more reliable estimates based on reflectance values.

To quantify the productivity of the eggplant, we used the indices calculated from the visible and near infrared reflectance of the leaves (ECI 1, NDVI, PRI, WI), the first of which is based on the red edge position (REP) caused by water stress. However, the strength of the relationship (R^2=0.03) did not justify that the plants were water stressed. Neither the NDVI nor the WI indices showed a statistically verifiable correlation. Of the indices only the PRI showed such variation in the drought period, so that its correlation with water supply was significant (R^2=0.52). In summary, the vegetation indices calculated from the data of few wavelengths have less information content and therefore are less suitable for precise characterization of the crops.

Of the different coloured nets, only the foreign product produced the promised shading effect (40%). In the Hungarian practice, the green net is the most commonly used by growers, it is the worst choice among the materials tested. The Hungarian-made green net was first used in ornamental production, where such photosynthetic activity loss is not problematic, especially in the case of foliage plants with not entirely green leaves. Colour nets with different shading capacity should be use specifically, according to species, cultivars, production modes and production sites and specifically adapted to the purpose of use (irradiation, ice, wind and pest protection). Probably not all requirements can be met with one material at the same time. Considering the quality parameters of the harvested fruits, yellow netting is recommended for growers in outdoor kapia paprika.

The soluble solids calibration model of processing tomatoes with 0.51 °Brix error is higher than the calibration model from the near infrared range alone. One of the probable reasons for this is the measurement uncertainty of the refractometer we used (±0.2 °Brix) and the other the lower sample number (n = 61). Despite the 6.6% error, however, I consider the calibration model to be capable of estimating the soluble solids content at the 4-6 °Brix interval, which can be further refined by measuring additional samples. Probably the estimation error of lycopene and total polyphenol content could be reduced by creating a larger sample element calibration library.

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Tóth Bence: A szamóca szárazanyagtartalmának meghatározása látható- és közeli infravörös spektroszkópiával, valamint antocianin tartalmának vizsgálata nagy hatékonyságú folyadék kromatográfiával.

Vajnai Anna: Színes árnyékoló hálók alkalmazásának hatása szabadföldi kápia paprikák termésmennyiségére és spektrális tulajdonságaira. OTDK I. Helyezett

Budavári Noémi: Amerikai heirloom paradicsomfajták beltartalmi értékeinek vizsgálata laboratóriumi és spektroszkópiás módszerekkel.

TDK consultancy

2013

Szántó Csongor: Az ipari paradicsom vízoldható szárazanyag-, likopin-, és polifenol-tartalmának meghatározása látható és közeli infravörös spektroszkópiával.

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