Visible and Near-Infrared Hyperspectral Imaging to Describe some Properties of Conventionally and Ecologically Grown Vegetables

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VISIBLE AND NEAR-INFRARED HYPERSPECTRAL IMAGING TO DESCRIBE SOME PROPERTIES OF CONVENTIONALLY AND ECOLOGICALLY GROWN VEGETABLES

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Background:

In recent years, the demand for organically grown agricultural products has significantly increased. Simultaneously, this increased the need for new approaches for quick evaluation and control of the quality of such type of agricultural production. There are numerous solutions used to monitor the food products aiming to assure their quality - analytical methodologies such as potentiometry conductivity, mass spectra screen-printed biosensors, etc. However, most of these methods are based on complex processing of samples, require expensive chemical reagents and highly qualified personnel, are time consuming and hard to implement operationally at mass production level. Along with the growing investments and research in the area of organic production, the importance for objective technique to evaluate the quality of organic products is also increasing. The potential of hyperspectral imaging as such techniques is discussed in this study.

Objective:

The aim of the study was to determine the opportunities to predict hydrogen ion concentration (pH), electrical conductivity (σ), reduction potential (ORP), and nitrates (NO_3) of tubers of potatoes (*Solanum tuberosum*) and carrots (*Daucus carota var. sativa*) using hyperspectral imaging approach. The potential of visible and near-infrared hyperspectral imaging as one of possible solutions for fast and free from subjectivism separation of organically and conventionally grown carrots was also investigated.

Materials and methods:

Totally, 140 carrots and 160 potatoes samples were used for investigation. Four different carrot varieties were represented in the study. Carrot samples for all varieties represented vegetables originating from organic and conventional farms. The samples of the tubers were prepared by cutting the tubers along into half using non-oxidizing knives. Thus one tuber sample was represented by one slice.

Hyperspectral scanning was conducted and hyperspectral images were acquired for each sample using Themis Vision Systems LLC portable scanning hyperspectral imaging camera VNIR400H which records object's spectral properties in the 400-1000 nm range with the sampling interval of 0.6 nm, producing 955 spectral bands.

Scanned samples were immediately submitted for laboratory measurements of NO_3, Ph, σ, and ORP, using standardized chemical tests.

In total, 140 reflectance curves for carrots and 160 reflectance curves for potatoes were constructed. In a spreadsheet, each reflectance curve was treated as a series of numbers (reflectance coefficients) in 955 wavebands in 400 nm – 1000 nm. These series of numbers were used for statistical analyses.

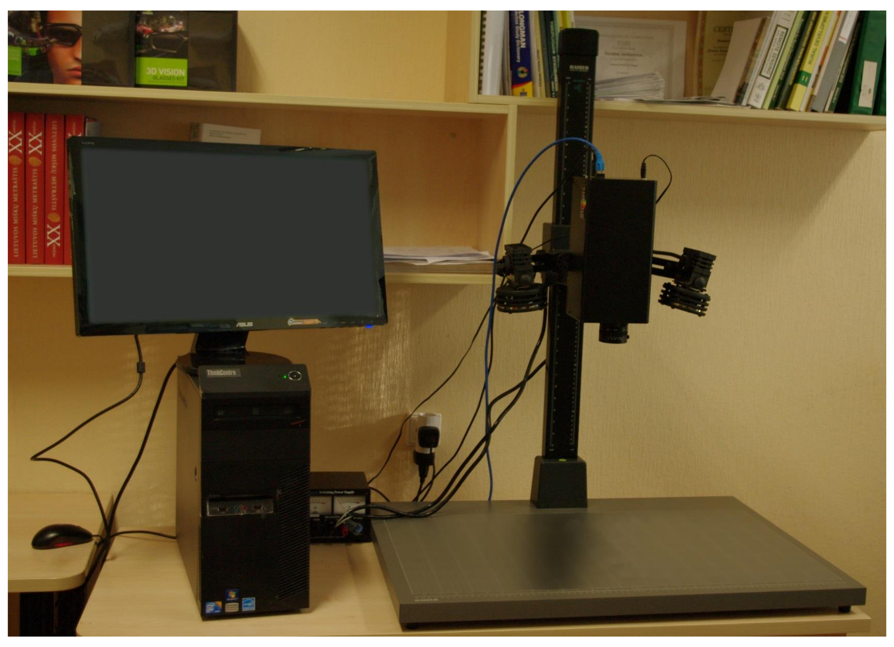
Principal component analysis (PCA) was employed to reduce the dimensionality and redundancy inherent in hyperspectral data and to compute the contribution of the reflectance coming from each wavelength to the principal components. The linear discriminant analysis (LDA) was applied for classification of conventionally and ecologically grown carrots by evaluating the possibilities to determine the method of growing. The following classification cases were tested:

1) Discrimination of organic and conventional samples at the species level, i.e. not taking into account the variety.
2) Discrimination of organic and conventional samples at the variety level.

The partial least squares regression (PLSR) was used to predict the pH, ORP, σ, and NO_3 in potatoes and carrots samples. The leave-one-out cross-validated R^2 were calculated for each model. All models were also validated using external data sets. The root mean square errors of prediction (RMSEP) and the mean absolute percentage error (MAPE) for prediction of each attribute were estimated as well. The classification accuracy was judged using the overall classification accuracy, "producer's and "user's" accuracies and the $\hat{\kappa}$ statistics, i.e. the metrics conventionally applied in remote sensing.

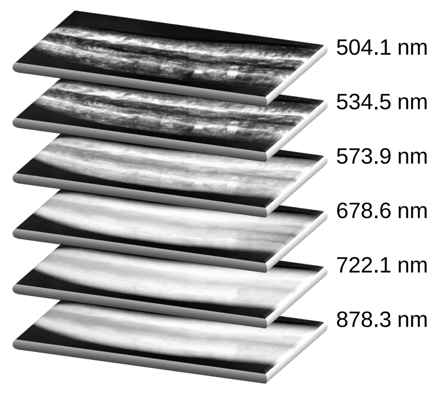
Tuber samples used for analysis

Variety	Number of samples	
	Organic	Conventional
Carrots (*Daucus carota var. sativa*)		
'Garduolės'	16	20
'Skalsa'	16	20
'Svalia'	16	16
'Šatrija'	16	20
Total	**64**	**76**
Potatoes (*Solanum tuberosum*)		
'Vineta'	40	-
'Valor'	40	-
'Melody'	-	40
'Laura'	-	40
Total	**80**	**80**

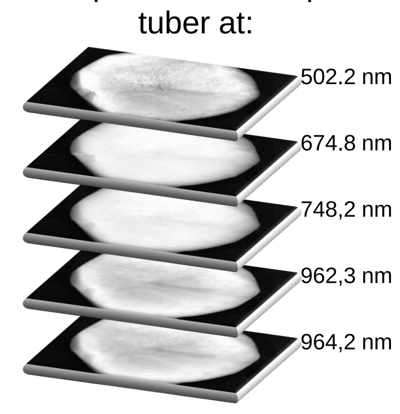


Hyperspectral scanning system Themis Vision VNIR400H-Hyper Visual®*

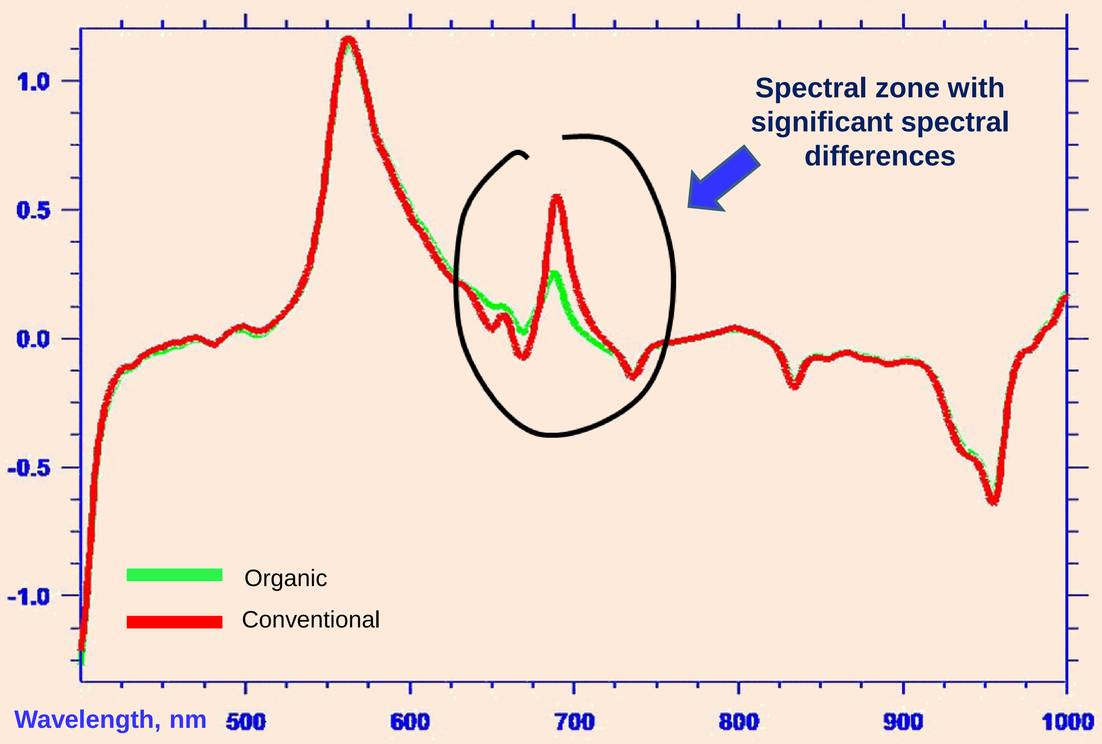
A sample of scanned carrot tuber at:



A sample of scanned potato tuber at:



Results: Separation between organically and conventionally grown carrots



Derivative hyperspectral curves of organically and conventionally grown carrots (1-st order derivation, variety 'Skalsa')

Optimal wavelengths for carrot variety and farming method separation (PCA)

Wavelenghts, nm	Spectral zone
722,1	Red (the red edge)
678,6	Red
573,9	Yellow
504,1	Green
878,3	Near infrared

Classification accuracy of different varieties of carrots and farming methods

Variety	Farming method	Classified as conventional	Classified as ecological	Producer's accuracy
'Garduolės'	conventional	18	2	90.0 %
	ecological	0	16	100 %
	User's accuracy	100 %	88.9%	
	Overall classification accuracy			**94,4%**
	$\hat{\kappa}$			**0.89**
'Skalsa'	conventional	20	0	100 %
	ecological	0	16	100 %
	User's accuracy	100 %	100 %	
	Overall classification accuracy			**100 %**
	$\hat{\kappa}$			**1.0**
'Svalia'	conventional	16	0	100 %
	ecological	0	16	100 %
	User's accuracy	100 %	100 %	
	Overall classification accuracy			**100 %**
	$\hat{\kappa}$			**1.0**
'Šatrija'	conventional	20	0	100 %
	ecological	0	16	100 %
	User's accuracy	100 %	100 %	
	Overall classification accuracy			**100 %**
	$\hat{\kappa}$			**1.0**

Classification accuracy of farming methods when the variety is not assumed

Farming method	Classified as conventional	Classified as ecological	Producer's accuracy
Conventional	54	22	71%
Ecological	20	44	68.8%
User's accuracy	73.0%	66.7%	
Overall classification accuracy			**70.0%**
$\hat{\kappa}$			**0.4**

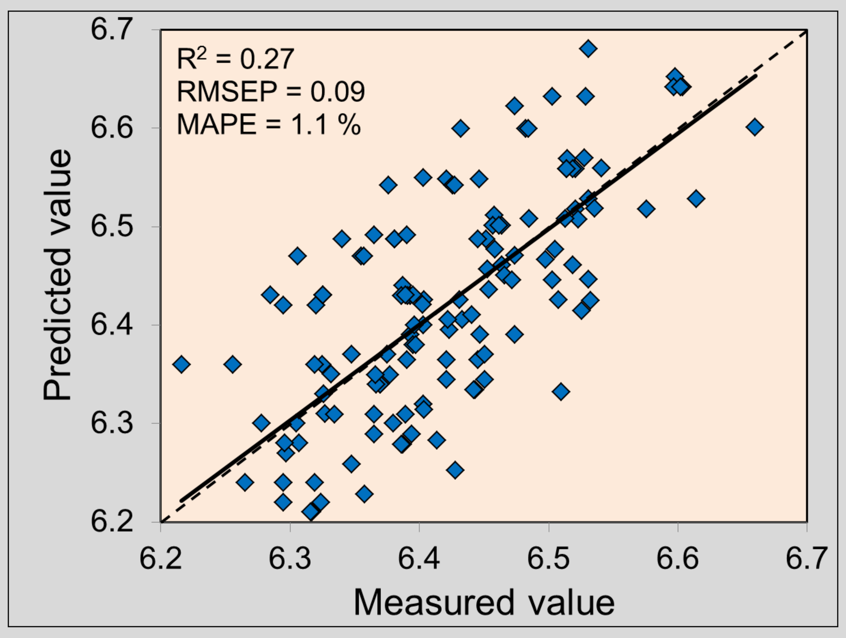
Conclusions:

1.The classification of conventionally and ecologically grown carrots, according to their hyperspectral reflectance, was very precise (overall classification accuracy 94.4 % to 100 %, $\hat{\kappa}$ 0.89 to 1.00) when carrot variety was taken into account.

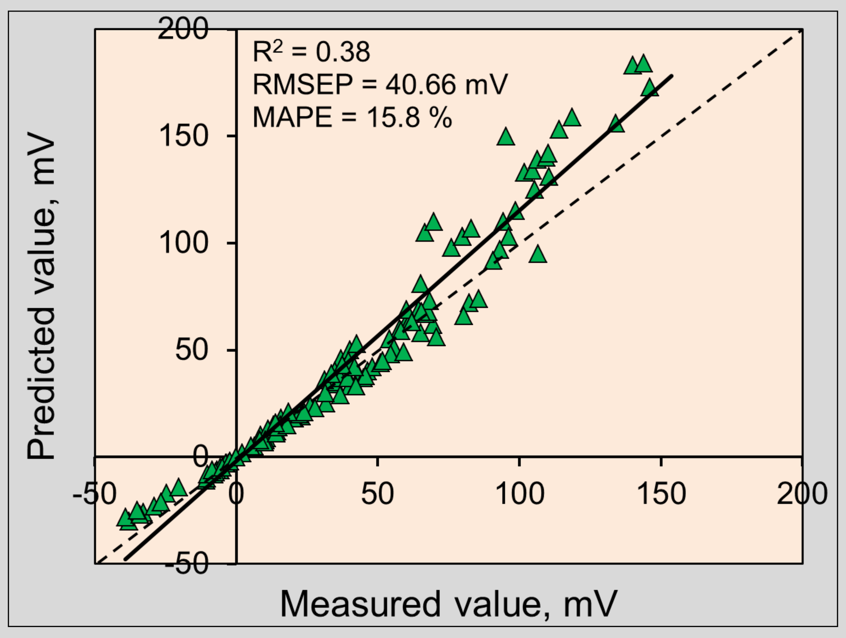
2. Hyperspectral reflectance data was found to moderately discriminate (overall classification accuracy 70 %, $\hat{\kappa}$ 0.40) the conventionally and ecologically grown carrots samples when carrot variety was not taken into account.

3. Very strong prediction potential was found for NO_3 (R^2 = 0.92), strong – for ORP, (R^2 =0.74), moderate – for pH (R^2 =0.46), and poor for σ (R^2 =0.18) in potato samples. Very strong prediction potential was found for σ (R^2 =0.88), strong - for NO_3 (R^2 = 0.77), moderate – for ORP (R^2 =0.38), and poor - for pH (R^2 =0.27) in carrot samples.

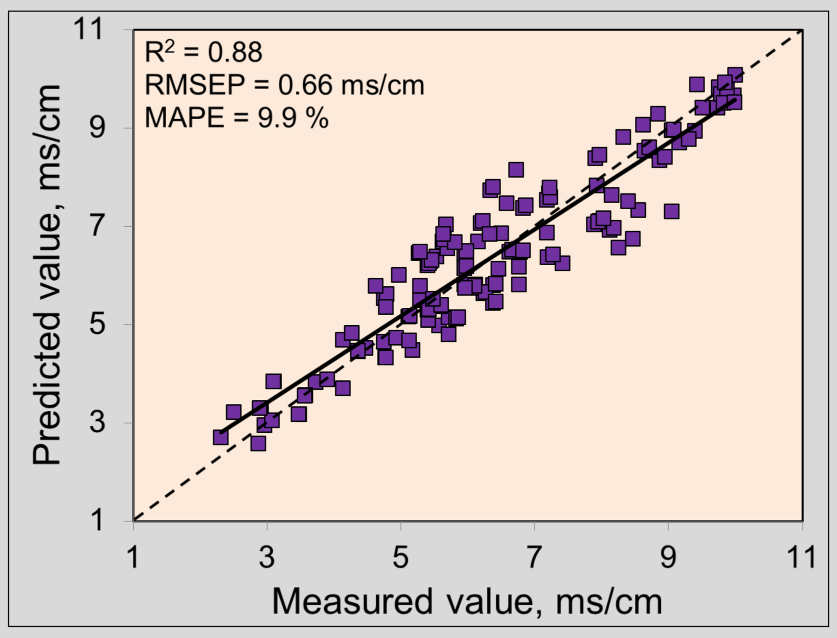
Relationships between predicted and measured pH, ORP, σ, and NO_3 in samples using hyperspectral imaging approach



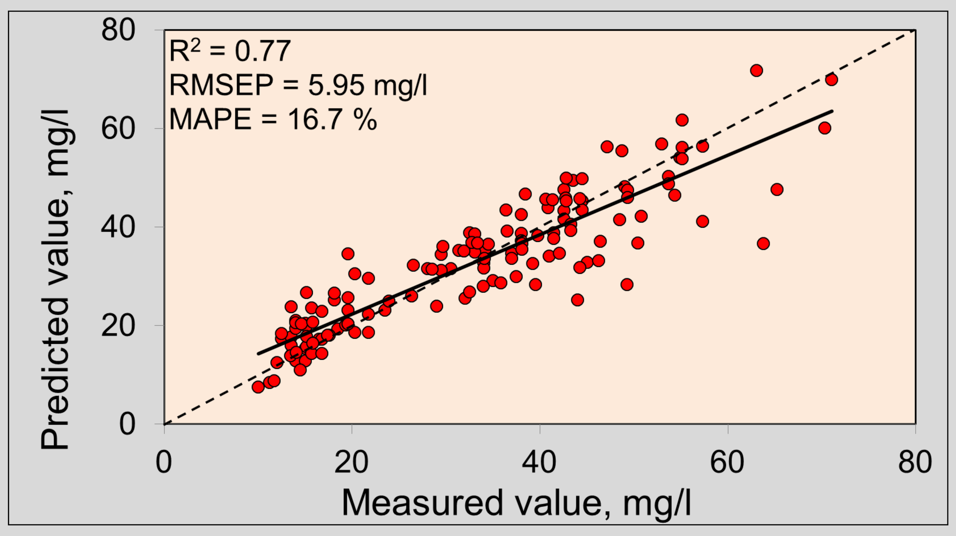
Relationships between predicted and measured pH in carrots according to their hyperspectral reflectance



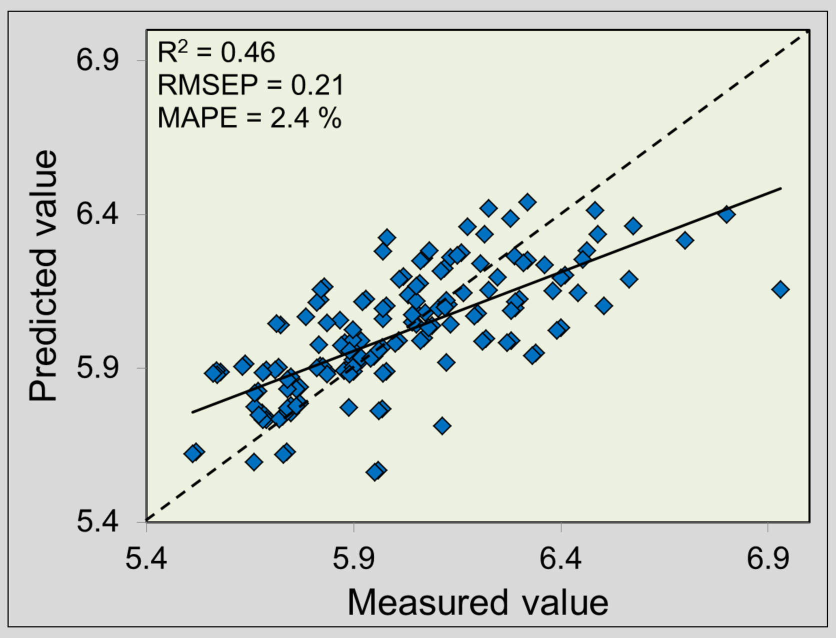
Relationships between predicted and measured ORP in carrots according to their hyperspectral reflectance



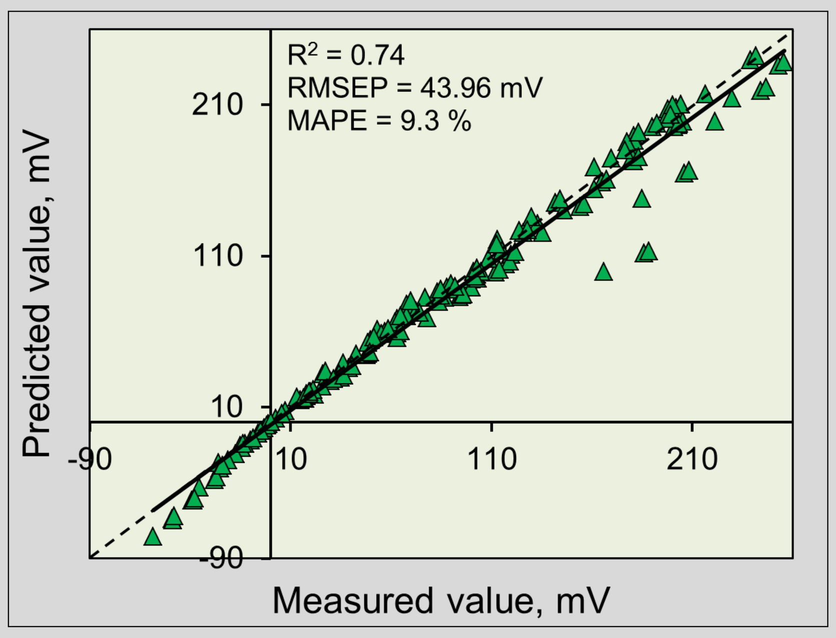
Relationships between predicted and measured σ in carrots according to their hyperspectral reflectance



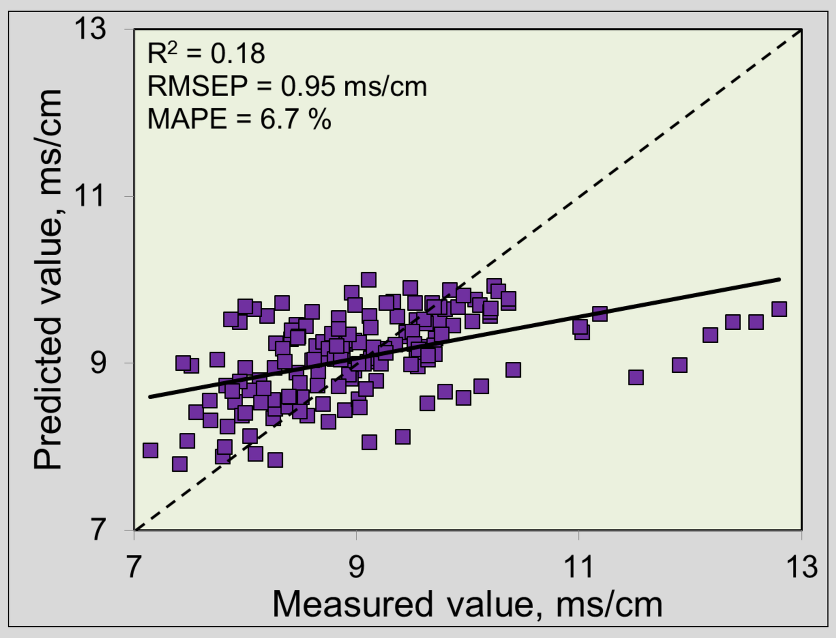
Relationships between predicted and measured NO_3 in carrots according to their hyperspectral reflectance



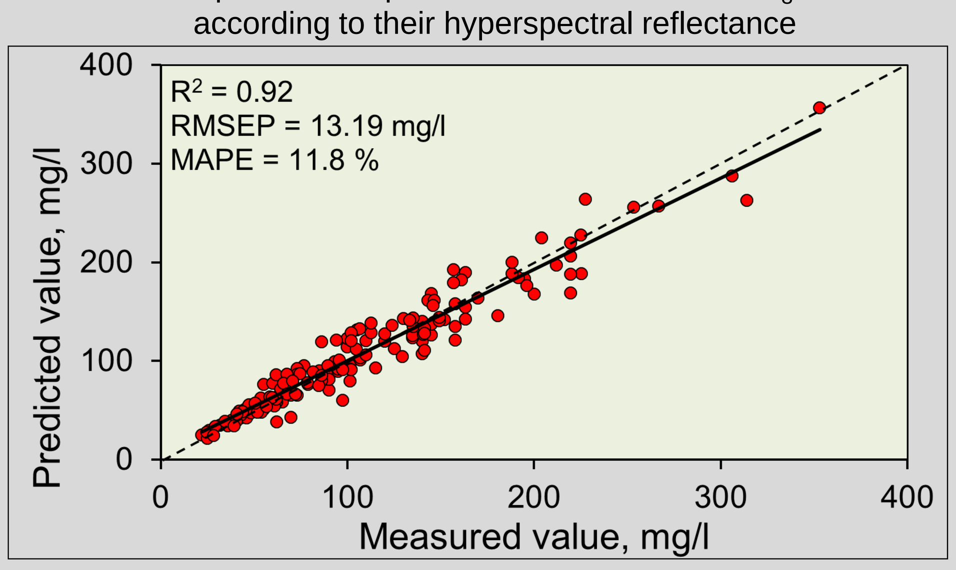
Relationships between predicted and measured pH in potatoes according to their hyperspectral reflectance



Relationships between predicted and measured ORP in potatoes according to their hyperspectral reflectance



Relationships between predicted and measured σ in potatoes according to their hyperspectral reflectance



Relationships between predicted and measured NO_3 in potatoes according to their hyperspectral reflectance