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Influence of harvest date on physicochemical properties and flesh image parameters of red-fleshed apples

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Introduction

- Red-fleshed apples with a pigmented pericarp are considered a novel fruit of great interest because of the enhanced content of beneficial compounds including anthocyanins and flavan-3-ols, as well as other polyphenolic compounds, acids, sugars, volatile components, and mineral elements.

- The harvest date can influence the maturity indices and physicochemical properties of apples.

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- There is limited available literature on the influence of harvest date on physicochemical properties and flesh image parameters of red-fleshed apples and correlations of different quality attributes of apples harvested on different dates assessed using non-destructive and destructive techniques. Demonstrating such relationships can be extremely important for researchers working in the field of non-destructive fruit testing.

- The application of parameters from apple flesh images obtained using a scanner or a digital camera for the prediction of apple physicochemical quality may be an objective approach without the need to use a laboratory, expensive equipment, or chemicals as in the case of chemical methods.

The objective of this study was to compare the physicochemical properties and image texture parameters of red-fleshed apples harvested at a weekly interval. The impact of the harvest date on color parameters *L**, *a**, and *b** of the skin and flesh, texture HMean for apple flesh images in individual color channels *R*, *G*, *B*, *L*, *a*, *b*, *X*, *Y*, *Z*, *U*, *V*, and *S*, dry mass, and chemical properties, including the content of sugars (sucrose, glucose, fructose, total sugars), sorbitol, acids (L-ascorbic acid, malic acid, citric acid, total acids), total pectins, and phenolic compounds (flavanols, dihydrochalcones, phenolic acids, flavonols, anthocyanins, total phenolic content) of red-fleshed apples 'Alex Red', 'Trinity', and 'Roxana' was evaluated.

The innovative part of this study was also related to the determination of correlations between selected physicochemical properties and texture parameters of flesh images in color channels *R*, *G*, *B*, *L*, *a*, *b*, *X*, *Y*, *Z*, *U*, *V*, and *S* of red-fleshed apples sampled on different harvest dates.

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Materials and methods

Materials

The apples belonging to three red-fleshed cultivars of ‘Alex Red’, ‘Trinity’, and ‘Roxana’ were harvested on two dates, August 31, 2021, and September 06, 2021. Fruits were sampled from the Experimental Orchard of the National Institute of Horticultural Research in Dabrowice (central Poland). For each cultivar and harvest date, 50 fully developed undamaged apples were selected. Immediately after harvesting, the apples were subjected to color measurements and imaging. Then, the same samples were used for chemical analyses.

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Figure 1. The images of whole fruit, half of an apple and a slice of red-fleshed apples 'Alex Red', 'Trinity', and 'Roxana' harvested on the I (August 31) and II (September 06) dates.

Measurements

Color measurements

- parameters *L** (lightness, 0 (dark) – 100 (light)), *a** (green (-) – red (+)), and *b** (blue (-) – yellow (+)) for apple skin and flesh

Image analysis

- 2172 image textures from images converted to individual color channels *R*, *G*, *B*, *L*, *a*, *b*, *X*, *Y*, *Z*, *U*, *V*, and *S*

Chemical properties

- dry matter
- sugars
- acids
- phenolic compounds
- pectin

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Statistical analysis

- the determination of statistically significant differences in color parameters, image texture HMean for each of the color channels *R*, *G*, *B*, *L*, *a*, *b*, *X*, *Y*, *Z*, *U*, *V*, and *S*, and chemical properties between red-fleshed apples sampled on both harvest dates separately for ‘Alex Red’, ‘Trinity’, and ‘Roxana’

- the determination of the linear relationships between the image parameters and physicochemical properties of red-fleshed apples (Pearson’s correlation coefficients (R), scatter plots)

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Results

Color parameters of red-fleshed apple skin

Table 1. The influence of harvest date on color parameters of the skin of red-fleshed apples

Sample	*L**	*a**	*b**
'Alex Red' - I harvest date	34.41a	21.57a	8.62a
'Alex Red' - II harvest date	33.06a	25.42b	11.39b
'Trinity' - I harvest date	35.32a	22.65a	10.95a
'Trinity' - II harvest date	32.81a	26.81b	11.83a
'Roxana' - I harvest date	40.05a	21.82a	18.67a
'Roxana' - II harvest date	39.37a	30.00b	21.95b

I harvest date - August 31, 2021, II harvest date - September 06, 2021
a,b - the same letters in the columns between the I harvest date and II harvest date for one apple cultivar denote no statistical differences

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Color parameters of red-fleshed apple flesh

Table 2. The color parameters of the flesh of red-fleshed apples sampled on different harvest dates

Sample	*L**	*a**	*b**
‘Alex Red’ - I harvest date	54.36a	29.06a	10.53a
‘Alex Red’ - II harvest date	50.50b	32.80b	11.88a
‘Trinity’ - I harvest date	51.56a	32.96a	11.11a
‘Trinity’ - II harvest date	47.04b	36.30b	12.69b
‘Roxana’ - I harvest date	71.91a	8.25a	11.80a
‘Roxana’ - II harvest date	69.52b	9.14a	13.97b

I harvest date - August 31, 2021, II harvest date - September 06, 2021
a,b - the same letters in the columns between the I harvest date and II harvest date for one apple cultivar denote no statistical differences

Flesh image textures

Table 3. The texture parameters of the flesh images of red-fleshed apples depending on the harvest date

Sample	RHMean	GHMean	BHMean	LHMean	aHMean	bHMean	XHMean	YHMean	ZHMean	UHMean	VHMean	SHMean
'Alex Red' - I harvest date	227.6a	107.3a	92.1a	166.7a	161.1a	152.3a	102.7a	74.7a	35.3a	99.1a	188.3a	126.0a
'Alex Red' - II harvest date	236.5b	106.8a	91.8a	169.8b	163.4b	154.1b	110.2b	78.6b	35.4a	97.6b	193.1b	135.6b
'Trinity' - I harvest date	231.8a	111.4a	93.9a	169.9a	160.8a	153.1a	107.8a	79.4a	37.4a	97.9a	188.6a	127.4a
'Trinity' - II harvest date	236.3b	99.3b	82.4b	166.0b	165.6b	156.4b	106.3a	73.2b	28.9b	95.4b	196.9b	143.4b
'Roxana' - I harvest date	217.8a	178.4a	150.0a	200.9a	134.9a	143.2a	131.5a	129.3a	87.8a	106.2a	149.0a	58.4a
'Roxana' - II harvest date	227.9b	166.9b	141.3b	197.0b	141.7b	145.2b	133.1a	123.1b	79.3b	103.9b	159.6b	96.0b

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Physicochemical properties of red-fleshed apples

Table 4. Selected physical and chemical parameters of red-flesh apples for two harvest dates.

Sample	Dry mass %	Sucrose $g \cdot kg^{-1}$	Glucose $g \cdot kg^{-1}$	Fructose $g \cdot kg^{-1}$	Sorbitol $g \cdot kg^{-1}$	Total sugars $g \cdot kg^{-1}$	L-ascorbic acid $mg \cdot 100g^{-1}$	Malic acid $mg \cdot 100g^{-1}$	Citric acid $mg \cdot 100g^{-1}$	Total acids $mg \cdot 100g^{-1}$	Total pectin $mg \cdot kg^{-1}$
'Alex Red' - I harvest date	15.1a	48.8a	1.6a	31.7a	3.5a	85.6a	17.5a	2004.0a	23.1a	2044.6a	6278a
'Alex Red' - II harvest date	15.0a	54.2b	1.7a	30.3b	4.7b	90.9b	17.1b	1844.7b	17.7b	1879.4b	6008b
'Trinity' - I harvest date	15.7a	62.0a	3.3a	38.1a	8.8a	112.3a	20.0a	1556.3a	23.9a	1600.3a	6196a
'Trinity' - II harvest date	15.4a	71.1b	4.0b	39.5b	13.5b	128.0b	24.0b	1631.2b	21.8a	1676.9b	6401b
'Roxana' - I harvest date	20.8a	51.0a	1.8a	33.5a	4.0a	90.6a	17.8a	1935.7a	19.4a	1972.9a	5912a
'Roxana' - II harvest date	22.3b	53.7b	1.9b	31.0b	4.4b	90.9a	21.9b	1944.1a	21.7a	1987.6a	6807b

I harvest date - August 31, 2021, II harvest date - September 06, 2021
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Chemical properties of red-fleshed apples

Table 5. The content of individual groups of phenolic compounds in red-flesh apples for two harvest dates.

Sample	Flavanols mg kg^{-1}	Dihydrochalcones mg kg^{-1}	Phenolic acids mg kg^{-1}	Flavonols mg kg^{-1}	Anthocyanins mg kg^{-1}	Total phenolic content mg kg^{-1}
'Alex Red' - I harvest date	75.4a	34.8a	59.6a	100.0a	266.3a	536.1a
'Alex Red' - II harvest date	76.2a	32.1b	58.0a	113.9b	221.6b	501.9b
'Trinity' - I harvest date	67.6a	35.3a	62.2a	102.6a	247.8a	515.5a
'Trinity' - II harvest date	91.6b	38.4b	57.6b	125.7b	260.0a	573.3b
'Roxana' - I harvest date	873.4a	51.6a	100.4a	50.2a	45.7a	1121.3a
'Roxana' - II harvest date	997.2b	50.2b	128.2b	72.4b	45.3a	1293.3b

I harvest date - August 31, 2021, II harvest date - September 06, 2021
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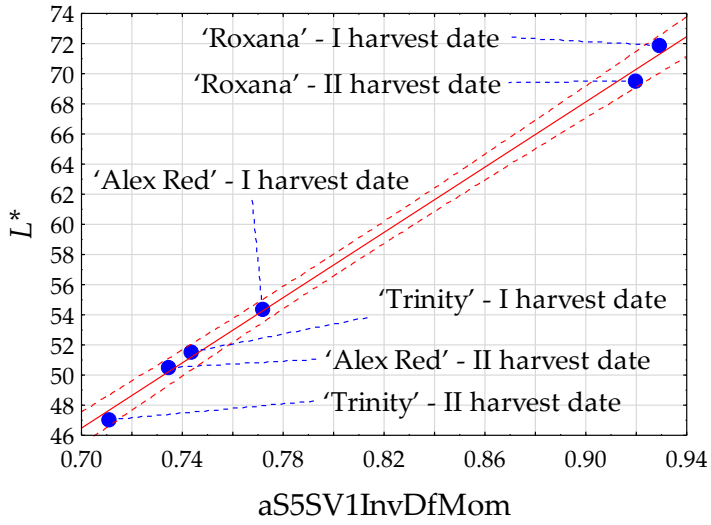
Relationship between image textures and physicochemical properties of red-fleshed apples collected on different harvest dates



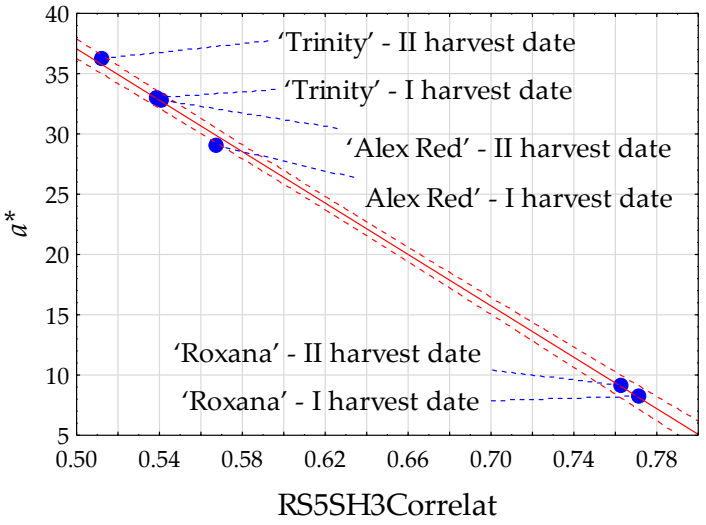


Figure 2. Scatter plots for color parameters with image textures of the flesh of red-fleshed apples harvested on different dates.
I harvest date - August 31, 2021, II harvest date - September 06, 2021
Blue dot - mean value; red dashed line - confidence interval (95%); solid red line - regression line; and blue dashed line - line connecting the mean value to the sample name.

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Relationship between image textures and physicochemical properties of red-fleshed apples collected on different harvest dates

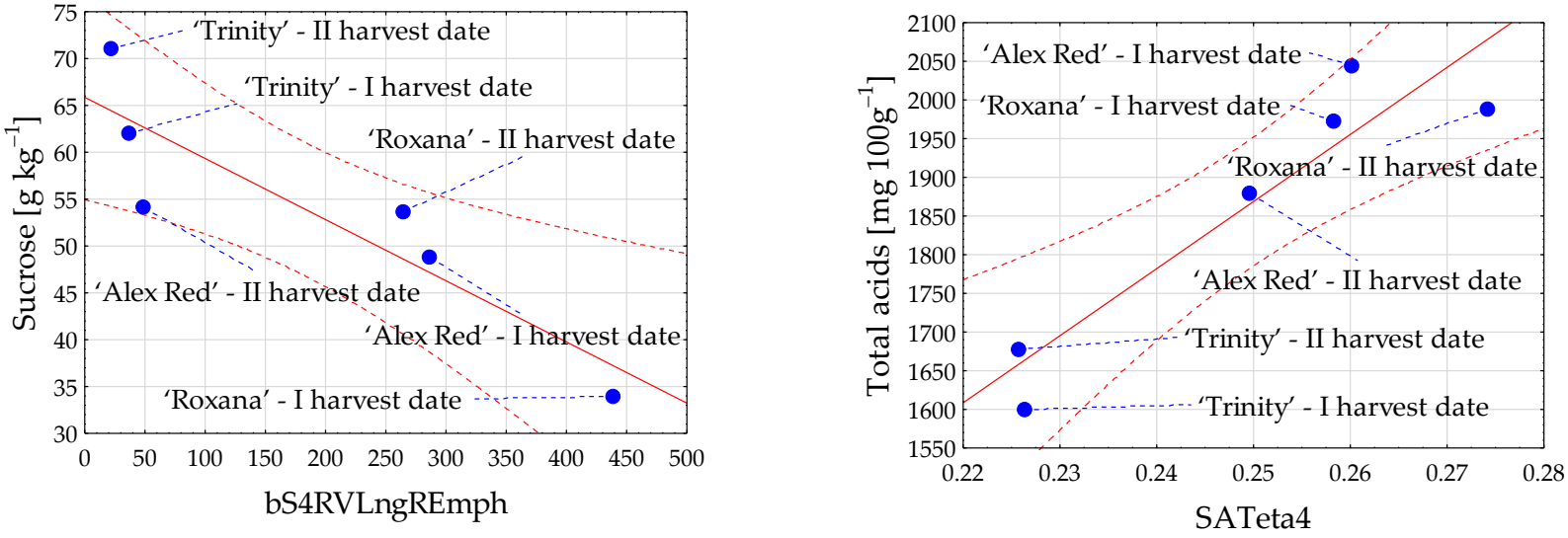

Figure 3. Scatter plots for sucrose and total acids with image textures of the flesh of red-fleshed apples harvested on different dates.
I harvest date - August 31, 2021, II harvest date - September 06, 2021
Blue dot - mean value; red dashed line - confidence interval (95%); solid red line - regression line; and blue dashed line - line connecting the mean value to the sample name.

Relationship between image textures and physicochemical properties of red-fleshed apples collected on different harvest dates

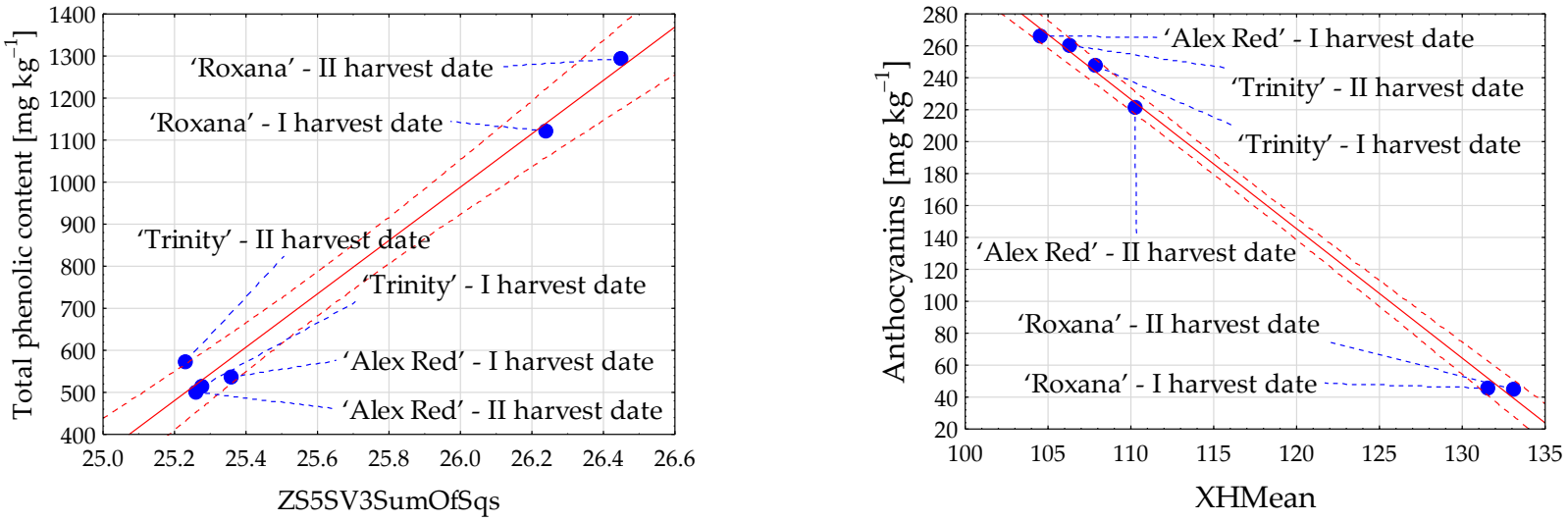

Figure 4. Scatter plots for selected phenolic compounds with image textures of the flesh of red-fleshed apples sampled on different harvest dates.
I harvest date - August 31, 2021, II harvest date - September 06, 2021
Blue dot - mean value; red dashed line - confidence interval (95%); solid red line - regression line; and blue dashed line - line connecting the mean value to the sample name.

Conclusions

The obtained results revealed the influence of harvest date on the physicochemical properties and image textures of red-fleshed apples. Statistically significant differences in color parameters *a** and *b** of apple skin, parameters *L**, *a** and *b** and image textures of the flesh, and the content of chemical compounds were noticed for selected cultivars.

Further experiments are needed for better understating the relationship between the content of bioactive compounds and cultivars/maturity/ripening stage.

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Furthermore, linear relationships between the image textures and physicochemical characteristics of red-fleshed apples were found.

Future studies may involve more cultivars harvested on more dates. Besides the raw material, the examination of the impact of harvest date on the properties of processed apples may be performed.

The regression equations for the estimation of the physicochemical properties of red-fleshed apples based on image parameters may be developed.

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