Spectral properties of strawberry plants

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*Summary:*6 strawberry varieties were studied in 3 different growing areas of different soil- and ecological properties in Hungary. We have measured the optical spectra of the leaves together with their nutrient content and performed sensory examinations on the deep frozen and melted fruit. The 6 varieties were Elsanta, Marianna, Spadeka, Symphony, Camarosa, and Raurica. The 3 sites were Újfehértó, Pölöske, and Kecskemét. Colour of the leaves was characterised by their lightness and dominant wavelength. Under non-optimal soil and ecological conditions the varieties could be distinguished by their colour – the leaves became lighter and more yellow. The fruits did not produce the genetically determined taste if the plant can not grow in optimal circumstances – we found a negative correlation between the leaf colour in flowering time and the fruit flavour. Leaf colour measurements performed in flowering time make it possible to improve fruit quality by changing the nutrient supply between flowering and ripening.

Key words: strawberry variety, growing area, leaf colour, leaf spectra, sensory examination

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Introduction

Strawberry (*Fragaria x ananassa* Duch.) is very important small fruit in Hungary. Strawberry is one of the earliest fresh fruits after the wintertime poor fruit supply in the market, and a delicious fruit not only for finished products, but also for ingredients to be included in complex foods such as ice-creams, cereals, dairy, confectionery, and bakery products (*Dermesonlouoglou*, 2006). The deep frozen products, jam, and preserved fruit are also popular.

Breeders have been producing several strawberry varieties with a broad range of capabilities. The most important qualities are the good level of resistance to Phytophtora cactorum, Ph. fragariae, Botrytis cinerae, and other strawberry diseases, high fruit quality, regular shape, long shelf-life, good smell and flavour, and attractive colour (*Roudeillac*, 1993). The different varieties, however, react differently to environmental and growing conditions.

Traditionally the evaluation of the yield of the plant is based on measurements of the fruit size and quantity and on organoleptic evaluation of the fruit quality (*Nestby*, 1998, *Miner* et al., 1997, *Darbellay* et al., 2000). However, this is a tedious process, moreover sensory evaluation always has a certain amount of subjectivity.

In an extensive statistical evaluation *Jacquemoud* et al., (1995) investigated the correlation of the biochemical properties of 73 plant leaves of different species with their optical properties. They found good prediction performances for the protein, cellulose, and lignin content. Based on these correlations, radiative transfer models (*Jacquemoud et al.,* 1996) were constructed which make it possible to calculate the simulated spectral response of a leaf model. Through the inversion of the model the leaf biochemical content can be estimated from its spectral response. Similar relations were found between the optical properties and leaf chlorophyll content (*Yamada & Fujimura*, 1991).

Leaf colour measurements provide a fast, cheap, and quantitative method of evaluation of the leaf nutrient status (*Buscaglia & Varco*, 2002). Reflectance measurements have shown to be a useful tool to identify the nutritional status of different plant species, said *Graeff & Claupein* (2003). *Espagňa-Boquera* et al., (2006) found spectral answer to the leaf N content, but a significant correlation was found only in the youngest leaves.

In this paper we examined the effect of the growing site on the optical spectrum of the leaves of different strawberry varieties. Moreover the correlation between the leaf colour measured at flowering time and the fruit quality was investigated. Our aim was to find those features of the optical spectra that give information on the nutrition status of the strawberry plant.

Materials and methods

We measured 6 strawberry cultivar`s leaf colour and nutrient content from 3 different growing areas. The growing system was the same for all places: raised bed, twin row,

covered with black woven plastic covers and drip irrigation system between the twin rows.

The ecological conditions of the 3 places are rather different, concerning both the soil parameters and the climatic conditions. The three places: *Pölöske* is situated in West-Hungary among the Zala-hills. The climate is moderately cold – moderately humid. The sunshine duration is 1900 hours. The annual mean temperature is 9,5 ℃, the summer mean temperature is 15,5 ℃. The summer mean of the absolute maximum temperature is 32,5 ℃, winter mean of absolute minimal is –17,5 ℃. The annual precipitation amount is about 700 mm/year. In summer: 440–450 mm. The type of the soil is clay brown forest soil. *Kecskemét* is situated in the middle of Hungary in the Alföld. The climate is moderately hot – dry. The sunshine duration is a little bit under 2100 hours. The annual mean temperature is 10,2–10,4 ℃. The summer mean of absolute maximum temperature is 34,2–34,5 ℃, in winter mean of absolute minimal is between –16,5 and –16,7 ℃. The annual precipitation amount is about 540–550 mm/year. In summer: 310–320 mm. The type of soil is light lime sandy soil. *Újfehértó* is situated in Eastern-Hungary called Nyírség. The climate is moderately hot (but near the moderately cold) – dry. The sunshine duration is nearly 2000 hours. The annual mean temperature is 9,5–9,6 ℃. The summer mean of the absolute maximum temperature is about 34 ℃, in winter mean of the absolute minimal temperature is –17 ℃. The annual precipitation amount is about 560–590 mm/year. In summer: 350 mm. The soil type is acidic sandy soil (*Marosi* et al., 1990).

We have collected leaf, and fruit samples.

Leaves: The collected samples were most – recently-matured leaves – those leaves that have reached maximum size, i.e. essentially stopped expanding size. These leaves also have changed from a juvenile light green colour to a dark green colour, which is very important to colour measuring. We collected the samples at flowering time. We picked 5 leaves per plant, measured their colour and the nutrient content: nitrogen, phosphorus and potassium. The nutrient content was measured in laboratory by standard chemical analysis techniques.

The colour of the leaves was measured by a MINOLTA-200 colorimeter.

This handheld instrument contains a built in light source and measures the reflection of the sample. Primary data are represented as CIE (Commission Internationale de l'Eclairage) tristimulus (X, Y, Z) values (*MacAdam,* 1981, *Wyszecki & Stiles,* 1982), where the sensitivity curves of the X, Y, and Z detectors match closely that of the red, green, and blue sensitive cones of the human eye. We calculated the λ_d dominant wavelength from the measured tristimulus values in the following way. First the XYZ -> L*a*b* -> LCH transformation was performed using standard procedures, where L is the lightness value, C is the chromaticity parameter, and H is the hue of the colour. The λ_d dominant wavelength associated to the measured tristimulus values is defined as the wavelength of that pure colour (i.e. a spectral distribution having an infinitely sharp peak at λ_d) which gives the same hue value as those measured, i.e. it is given as the solution of the following equation:

$$H_{leaf} = H(\lambda_d) \tag{1}$$

The λ_d solution of this nonlinear equation was computed numerically for each measured H_{leaf} value (MINOLTA CR-200).

All calculated λ_d values lie between the 499 nm (green) and 578 nm (yellow) values. In this wavelength range Eq. (1) can be linearized with a good approximation ($R^2=0,9975$),

$$\lambda_d = -0,7765\ H_{leaf} + 648,48\ [nm] \tag{2}$$

The introduction of the dominant wavelength has several advantages. On the one hand while the tristimulus values are "antropomorph" by their very definition – matching the sensitivity of the human eye – calculating the dominant wavelength this antropomorph factor is "transformed out" in some extent, because the wavelength is a physical parameter of the light. On the other hand the use of λ_d makes us possible to
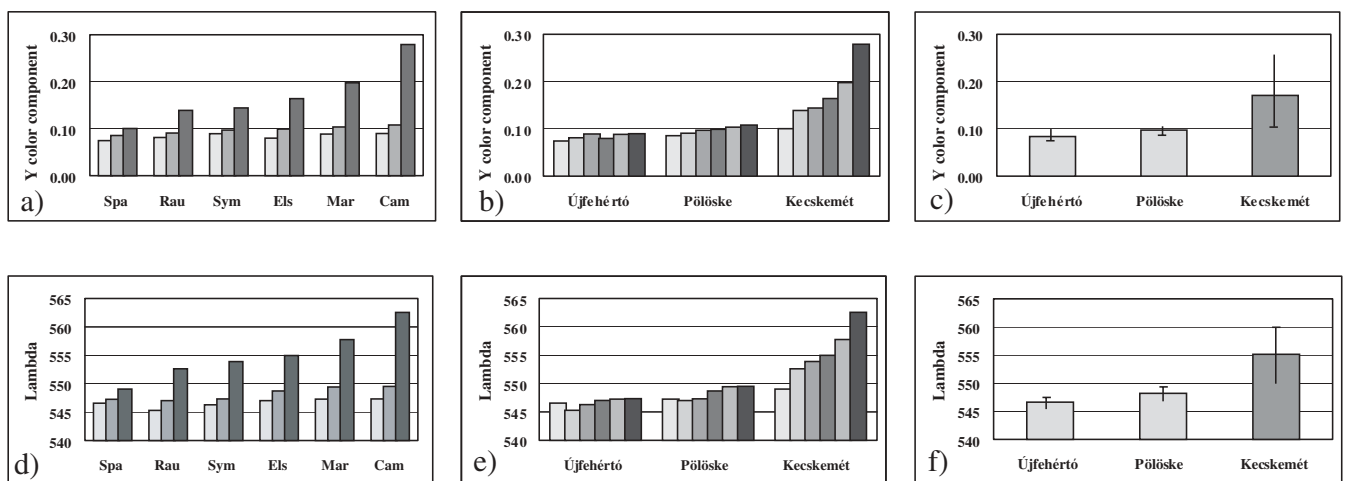
Figure 1 Leaf colour parameters as a function of cultivar and growing site. The upper (lower) row shows the lightness (dominant wavelength), respectively. (a) and (d): Effect of the cultivar. The three growing sites are shown by different shades of grey. (b) and (e): Effect of the growing site. The six cultivars are shown by different patterns. (c) and (f): The height of the columns show the average and the error bars show the standard deviation. The wavelength is measured in nanometer.

characterize the hue of the colour of the leaves with only one parameter. The other important characteristics of the leaf optical reflection is the amount of the total reflected light. In this paper we use the Y (green) tristimulus component as a measure. (See the Discussion below for details). Hence the optical properties of each leaf sample is represented as a (Y, λ_d) pair, where Y measures the lightness and λ_d measures the colour hue.

Fruits: The fruit samples were collected from the second and third picking. After the picking the berries were kept in deep fridge at –20 ℃. Before the procedure of sensory examination, the samples were put in a 10% sugar solution. The taste panel stood about 18–20 persons. At the judging four parameters were estimated: size and form, colour, flavour-smell, and fruit firmness (*Códex*, 2000). The characters were graded between 1–5 point (with a possibility of giving half a point). *Dirinck* et al*., (1981.*

) examined strawberry fruits with similar methods but on fresh fruit and between 1–9 value. *Darbellay* (2000) and *Wozniak* et al*., (1996) have used a similar method to valuate the strawberry varieties' quality.

By its very sensory nature organoleptic examination does not give absolute, but only relative results for the judged parameters. This means that only the differences between the ranks given during the same judgement can be taken into account. Since the samples from the 3 growing sites were evaluated in 3 different judgements (but partly by the same persons) a special data procession was necessary in order to compare the results. To this end the variety Elsanta was chosen as a standard variety and the grade differences relative to Elsanta were calculated.

The data processing was made by ANOVA method (*Sváb*, 1965).

Results

Leaf colour measurements

Figure 1 shows the (Y, λ_d) colour parameters (lightness and hue) of the leaves as a function of the growing site and the variety. The upper row shows the Y lightness parameters and the lower row shows the λ_d hue parameters, the numerical values are given in Table 1, and 3. a(d). shows how the lightness (hue) values change for each variety for the 3 places. b(e) shows the same data grouped by the site – this shows the variation of the colour at each particular growing site. We can see that while at Újfehértó the colour of the varieties shows only a small scattering, at Kecskemét, however, the colour of the different varieties have a considerable scattering. This is further demonstrated at c(f) where the average and the standard deviation of the lightness (hue) parameters are displayed (*Table 1*) as the function of growing site.

As can be seen in *Tables 2* and *4*, both the effect of the variety and site are significant at 0.1% level. The interaction of the two factors is also significant at this level.

Though both the variety and the growing site does have a significant effect on the Y and λ_d colour parameters, it is also

Table 1 The lightness as a function of cultivar and growing site.

Y	Újfehértó	Pölöske	Kecskemét
Spadeka	0.0730	0.0842	0.0991
Raurica	0.0799	0.0894	0.1375
Symphony	0.0879	0.0956	0.1428
Elsanta	0.0784	0.0977	0.1626
Marianna	0.0871	0.1021	0.1962
Camarosa	0.0883	0.1066	0.2777
Average	0.0825	0.0959	0.1693
St. Dev.	0.0063	0.0082	0.0619
CV%	7.6%	8.5%	36.6%

Table 2 Analysis of variance results for the lightness parameter

Y	$SD_{5\%}$	Sign. Level
Variety	0.0178	***
Site	0.0126	***
interaction		***

Table 3 The dominant wavelength (nm) as a function of cultivar and growing site.

λ_d	Újfehértó	Pölöske	Kecskemét
Spadeka	546.4	547.1	548.9
Raurica	545.2	546.9	552.5
Symphony	546.2	547.2	553.8
Elsanta	546.9	548.6	554.8
Marianna	547.2	549.3	557.6
Camarosa	547.2	549.4	562.4
Average	546.5	548.1	555.0
St. Dev.	0.78	1.15	4.62
CV%	0.14%	0.21%	0.83%

Table 4 Analysis of variance results for the dominant wavelength parameter

	$SD_{5\%}$	Sign. Level
Variety	1.29	***
Site	0.91	***
Interaction		***

important to know, for which particular pairs of variety and for which particular pairs of the growing site the difference of the measured Y and λ_d colour parameters is significant. This is accomplished by comparing the $Y_{vi} - Y_{vj}$, $Y_{ai} - Y_{aj}$, $\lambda_{vi} - \lambda_{vj}$, and $\lambda_{ai} - \lambda_{aj}$ differences with the corresponding $SD_{5\%}$ levels *(cf. Table 2. and Table 4.)*, where "vi" and "vj" are the variety index (1 for Spaeka, 2 for Raurica, …, and 6 for Camarosa) and "ai" and "aj" are the growing site index (1 for Újfehértó, 2 for Pölöske, and 3 for Kecskemét). If the absolute value of the difference is greater than the corresponding $SD_{5\%}$ level, i. e. their quotient is greater than one, then the corresponding difference is significant. *Tables 5, 6, 7,* and *8* show the results of this analysis as triangular matrices. (The sign of the difference changes when the two indices are exchanged, e.g. $(\lambda_{vi} - \lambda_{vj}) = - (\lambda_{vj} - \lambda_{vi})$,

Table 5 Significance levels of the "site" factor pairs on the "lightness" colour parameter. Significant differences are shown with a grey background.

		Újfehértó	Pölöske	Kecskemét
	Y	0.0825	0.0959	0.1693
Újfehértó	0.0825		1.1	6.9
Pölöske	0.0959			5.8
Kecskemét	0.1693			

Table 6 Significance levels of the "variety" factor pairs on the "lightness" colour parameter. Significant differences are shown with a grey background.

Újfehértó	Y	Spadeka	Raurica	Symphony	Elsanta	Marianna	Camarosa
Y		0.0730	0.0799	0.0879	0.0784	0.0871	0.0883
Spadeka	0.0730		0.4	0.8	0.3	0.8	0.9
Raurica	0.0799			0.5	-0.1	0.4	0.5
Symphony	0.0879				-0.5	0.0	0.0
Elsanta	0.0784					0.5	0.6
Marianna	0.0871						0.1

Pölöske	Y	Spadeka	Raurica	Symphony	Elsanta	Marianna	Camarosa
Y		0.0842	0.0894	0.0956	0.0977	0.1021	0.1066
Spadeka	0.0842		0.3	0.6	0.8	1.0	1.3
Raurica	0.0894			0.3	0.5	0.7	1.0
Symphony	0.0956				0.1	0.4	0.6
Elsanta	0.0977					0.2	0.5
Marianna	0.1021						0.2
Camarosa	0.1066						

Kecskemét	Y	Spadeka	Raurica	Symphony	Elsanta	Marianna	Camarosa
Y		0.0991	0.1375	0.1428	0.1626	0.1962	0.2777
Spadeka	0.0991		2.2	2.5	3.6	5.5	10.0
Raurica	0.1375			0.3	1.4	3.3	7.9
Symphony	0.1428				1.1	3.0	7.6
Elsanta	0.1626					1.9	6.5
Marianna	0.1962						4.6
Camarosa	0.2777						

hence the lower part of the matrix would not give us additional information.) A number "1.0" means that the corresponding difference is equal to $SD_{5\%}$. Numbers less than one mean that the difference of the given factor pair is not significant. Numbers greater than one (enhanced with grey background on the tables) mean that the difference is significant. Greater numbers denote a larger significance of the given factor pair

We can see in *Tables 5* and *7* that the effect of the growing

Table 7 Significance levels of the "site" factor pairs on the "dominant wavelength" colour parameter. Significant differences are shown with a grey background.

		Újfehértó	Pölöske	Kecskemét
	λ_d	546.5	548.1	555.0
Újfehértó	546.5		1.7	9.3
Pölöske	548.1			7.6
Kecskemét	555.0			

site on both the lightness and the dominant wavelength parameter is significant for all site pairs but the significance is much greater when one of the sites if Kecskemét in the comparison.

Tables 6 and *8* show that the effect of the variety is not significant for all combinations and the growing site has a marked effect on how distinguishable are the varieties. (This can also be seen on *Tables 2* and *4* which show that the interaction of the "site" and "variety" factors if also significant).

At Újfehértó, there are no significant differences between the colours of the varieties (this is true for the lightness and for the dominant wavelength). At Pölöske, however, we can see already some significant differences. Concerning the lightness factor, the variety Spadeka is distinguishable from Marianna and Camarosa in its lightness. We can see in *Table 8* that the dominant wavelength difference matrix in Pölöske is a block matrix, i.e. if we divide the 6 varieties into two groups: Spadeka, Raurica, Symphony and Elsanta, Marianna, Camarosa, then we can observe no significant differences in λ_d within the two groups but the inter group differences are significant. At growing site Kecskemét there are significant colour differences in between all varieties but the Raurica-Symphony pair in lightness and the Symphony-Elsanta pair in λ_d.

Sensory examination

Now we turn to the investigation of the sensory examination results. As we explained above, the sensory results can be "normalized" by recording the grade differences relative to a standard variety. We choose Elsanta for this purpose. In order to study the effect of the growing site we calculated the Pölöske-Újfehértó and Kecskemét-Újfehértó grade differences, i.e. *Table 9* shows how the flavour-smell grade of a given variety changes at the different growing areas.

If we compare the such calculated Kecskemét-Újfehértó flavour-smell grade differences to the measured leaf lightness at Kecskemét, *Figure 2*, a very good correlation is seen between these two quantities. As concerns the Pölöske-Újfehértó difference and the other sensory parameters, smaller correlation coefficients were found.

Discussion

Our leaf colour measurements show that in optimal ecological and nutritional conditions the leaf colour of the different strawberry cultivars shows only a small variation – the

Table 8 Significance levels of the "variety" factor pairs on the "dominant wavelength" colour parameter. Significant differences are shown with a grey background.

Újfehértó		Spadeka	Raurica	Symphony	Elsanta	Marianna	Camarosa
	λ_d	546.4	545.2	546.2	546.9	547.2	547.2
Spadeka	546.4		-1.0	-0.2	0.4	0.6	0.6
Raurica	545.2			0.8	1.3	1.5	1.6
Symphony	546.2				0.6	0.8	0.8
Elsanta	546.9					0.2	0.2
Marianna	547.2						0.0
Camarosa	547.2						

Pölöske		Spadeka	Raurica	Symphony	Elsanta	Marianna	Camarosa
	λ_d	547.1	546.9	547.2	548.6	549.3	549.4
Spadeka	547.1		-0.2	0.0	1.1	1.7	1.7
Raurica	546.9			0.2	1.3	1.9	1.9
Symphony	547.2				1.1	1.6	1.7
Elsanta	548.6					0.6	0.6
Marianna	549.3						0.1
Camarosa	549.4						

Kecskemét		Spadeka	Raurica	Symphony	Elsanta	Marianna	Camarosa
	λ_d	548.9	552.5	553.8	554.8	557.6	562.4
Spadeka	548.9		2.7	3.7	4.6	6.7	10.4
Raurica	552.5			1.0	1.8	4.0	7.7
Symphony	553.8				0.8	3.0	6.7
Elsanta	554.8					2.2	5.9
Marianna	557.6						3.7
Camarosa	562.4						

Table 9 Organoleptic flavour-smell differences for Pölöske-Újfehértó and Kecskemét-Újfehértó, relative to Elsanta.

Flavor-smell	P-U	K-U
Spadeka	-0.35	0.45
Raurica	0.00	0.40
Symphony	-0.15	0.15
Elsanta	0.00	0.00
Marianna	-0.10	-0.30
Camarosa	-1.00	-0.60
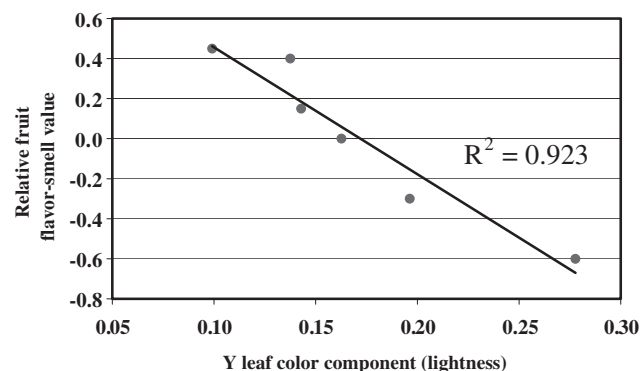
Figure 2 Comparison of measured leaf lightness parameter and sensory fruit flavour-smell grade at Kecskemét growing site. See the text for details.

leaves are all green. Indeed, *Tables 1* and *3* clearly show that the standard deviation is small at Újfehértó. As we can see in *Tables 6* and *8* no significant differences were obtained in neither the lightness, nor in the dominant wavelength. The different cultivars, however, react differently to non-optimal conditions, and this makes the standard deviation of the measured colour parameters large at Kecskemét. The leaf colour parameters of the different cultivars are significantly different under these conditions. This means that the sensitivity of the varieties to the growing area shows a large variation – the Spadeka variety tolerates the change of the site the best and the Camarosa variety shows the biggest sensitivity to the growing site.

We choose to characterise the lightness of the leaves with the Y tristimulus component because of two reasons. First, the lightness L is calculated in the L*a*b* colour system from Y as $L = 116\,(Y/Yr)^{1/3} - 16$, and second, we found it more suitable to use Y instead of $Y^{1/3}$ for our purposes because this nonlinear transformation improved the significance levels in the ANOVA calculation.

The dominant wavelength measurements of Pölöske leaves (*Table 8*) show that the 6 cultivars can be divided into two groups: Spadeka-Raurica-Symphony and Elsanta-Marianna-Camarosa. We observed no significant intra-group colour differences and significant inter-group differences.

We found a very good correlation (*Figure 2*) between the measured leaf colour at growing site Kecskemét and the result of the sensory examination for the flavour-smell of the fruit. This significant result makes a connection between an objective measurement performed by an instrument and an average of sensory examination results subjectively given by a panel of observers.

The genetically determined leaf colour depends on the optimal nutrition (*Ulrich,* 1980). Our soil analysis results showed (*Table 10*) high P and K levels in Kecskemét and these high levels prevented the plant to take up the other nutrient elements which caused the discolouration of the leaves and the poorer flavour of the fruit.

Conclusions

Finally we can say that the effect of the growing area is very important because it makes a strong influence to the colour of the strawberry leaves. At the places where the circumstances are not optimal for the plants, their leaves'

Table 10 Soil analysis results for the three growing areas.

Soil nutrient levels							
	pH_{H_2O}	Ca_{CO_3} %	EDTA-Cu mg/kg	EDTA-Fe mg/kg	AL-P_2O_5 mg/kg	AL-K_2O mg/kg	Humus %
Pölöske	7.18	0.82	0.17	8.37	333	160	5.63
Újfehértó	5.99	0	2.11	8.01	230	237	0.97
Kecskemét	7.94	11.5	0.06	1.87	1071	634	3.33

colour has greater differences than in case of an optimal place.

By careful study of the sensory examination data we have found that the Újfehértó growing site was the best for the examined strawberries, Pölöske was optimal either, and in Kecskemét we found a strong negative correlation between the leaf colour and the flavour of the fruit. If the leaf colour of the strawberry plant is lighter and more yellow in flowering time, it anticipates a degradation of the fruit flavour. This result makes it possible to foresee the fruit quality based on simple, but objective leaf colour measurements. A strawberry plant with unsatisfactory nutrient supply can not produce the genetically determined fruit quality. The unsatisfactory nutrient supply causes the discoloration on the plant leaf which is measurable by the colorimeter. The more yellow the leaf the less good tasty the fruit is.

When the light green or yellow-green leaves are visible on the plants at flowering time, there is still possibility to intervene and change the nutrient supply, in order to improve the strawberry fruit quality.

This paper presents the first result of a complex experiment with three different growing areas and 6 strawberry varieties, and different nutrient supplies. Results for the connection of the nutrient content and leaf colour, and fruit quality will be published later.

Acknowledgements

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