7 : 224(2), 181(20), 153(3), 152(23), 136(85), 110(55), 81(60), 72(91), 69(25), 43(100).

8 : 296(10), 265(20), 264(32), 253(6), 204(40), 153(16), 152(94), 151(24), 110(100), 109(26), 57(17), 43(28).

9 : 294(21), 263(26), 262(35), 234(45), 204(100), 202(38), 193(30), 192(69), 191(50), 189(36), 177(38), 175(39), 164(50), 153(17), 152(60), 110(75), 59(83), 43(65).

Acknowledgement :

The authors wish to thank Prof. P.E. Eaton and Prof. W.G. Dauben for supplying samples of the photodimers of α, β-unsaturated ketones.

BIBLIOGRAPHY

1. P.E. EATON, *Accounts Chem. Res.*, **1**, 50 (1968).
2. P.G. SAMMES, *Quart. Rev., Chem. Soc.*, 47 (1970) and references cited therein.
3. R.C. COOKSON, R.R. HILL, J. HUDEC, *J. Chem. Soc.*, 3043, 3062 (1964).
4. P.E. EATON, *J. Am. Chem. Soc.*, **84**, 2344 (1962).
5. W.G. DAUBEN, G.W. SHAFFER, N.D. VIETMEYER, *J. Org, Chem.*, **33**, 4060 (1968).
6. P. SINGH, *Tetrahedron Letters*, **16**, 1071 (1971).
7. P. SINGH, *J. Org. Chem.*, **36**, 3334 (1971).
8. H. ZIFFER, H.M. FALES, G.W.A. MILNE, F.H. FIELD, *J. Am. Chem. Soc.*, **92**, 1597 (1970).

Rijksuniversiteit Gent
Fac. Landbouwwetenschappen
Lab. Organische Scheikunde
Coupure 533
B-9000 Gent (Belgium)

Laboratorium voor Tuinbouwplantenteelt
(Laboratory for Horticulture)
Coupure Links 533 — B 9000 Gent. Belgium
Directeur : Prof. Dr. Ir. G. BOESMAN, R.U.G.

QUALITY CONTROL OF HORTICULTURAL PRODUCTS BY MEANS OF PHYSICAL COLORIMETRY IN COMPARISON WITH OTHER METHODS OF COLOUR EVALUATION [1] [2]

Mededelingen Faculteit Landbouwwetenschappen, Gent, Belgium volume 39, 1974, pp. 1655-1665

by

Boesman, G. and Flamée, M. [3]

Introduction

It cannot be denied that colour is a prominent factor in the evaluation of the quality of horticultural products. In scientific research as for practical purposes various, more or less effective methods are used to determine the surface colour. The most simple among these methods are based either on the mentioning of a colour name without much critical judgement or exact definition, or on the use of colour standards with which the colour considered is compared visually. During the last years can be noticed that more exact methods of colour description and comparison are applied. Therefore more or less complicated apparatus are necessary.

In the recent past our laboratory has examined both complex and simple methods in order to find a practical method for colour description and judgement of plantmaterial, especially horticultural products, without losing too much of a reasonable accuracy.

For this purpose, several research methods of colour determination on the one side and a wide gamut of agricultural and horticultural products, such as flower crops (carnations, roses, ...) vegetables (tomatoes, leek, celery, ...) and some apple varieties,

(1) Study done with the financial aid of the "Instituut tot Aanmoediging van het Wetenschappelijk Onderzoek in Nijverheid en Landbouw" (I.W.O.N.L.)

(2) Paper presented at the XIX^th International Horticultural Congres, Warszawa, Poland, 1974.

(3) Research assistant, "Centrum voor de Studie van de Sierplantenteelt — Sectie V" (I.W.O.N.L.)

on the other side were tested. In addition, a lot of ornamental trees were involved in this research, so that we dispose of a start of a catalogue on the colour of the leaves of a considerable number of species and varicties. We think that in this way we contributed to the specification, the judgement and the comparison of the colour of leaves, flowers, fruits and other plant parts.

From the beginning we were aware of the fact that most of the research methods, as well the subjective (simple) as the objective (more complicated) ones, how precise or interesting they can be, are very difficult to put into practice. Therefore we tried to combine accuracy and utility.

As an example of the useful application of colorimetry the quality control of horticultural products can be considered. The following data are dealing with colour in function of quality judgement, they constitute a short synthesis of the data of which we dispose. We will confine to the following subjects :

— the quality judgement of carnations and roses as cut flower (vase life).
— the colour changes occuring on ripening tomatoes influenced by the nutrient condition.

Results and discussion

From various scientific studies is known that the flower colour changes according to the development stage, fertilisation, environmental conditions, rootstock, storage of the cutted product.

With a few examples it is the aim to show that the colour differences occuring can be expressed in an objective manner. In what follows, the colour specifications for some cut flowers of the carnation variety 'Red Scania' and the rose variety 'Baccara' after 0, 2, 4 and 6 days are given. The cutted flowers were placed in tap water without preservatives or with a commercial preservative product.

The colour is expressed here according to the CIE system (*) in x, y, z and Y (Boesman, 1964; Boesman & Flamée, 1970). The Y-value indicates the lightness, the x, y and z-values give an indication of the relative amount of the red (x), green (y) and blue (z) reference colour respectively.

In table 1 the CIE specifications for two series of flowers of the rose variety 'Baccara' are given, the values are represented in fig. 1, which is a detail of the chromaticity diagram. The purpose of these data is not to compare the mutual colour of the flowers

(*) CIE : Commission Internationale d'Eclairage

of both series but to follow the run off of the blooming. In all cases the Y-value (lightness) as the z-value (relative blue amount) is increasing, the x-value is decreasing. The y-value is not discussed here, for the green amount of the colour is of minor importance in this case.

TABLE 1

CIE-specifications for 'Baccara' describing the flower colour after several days in tap water or with preservatives

days	series 1			series 2		
	x	z	Y	x	z	Y
	Tap water without preservatives					
0 d.	0.593	0.078	10.86	0.622	0.057	8.16
2 d.	0.556	0.119	14.00	0.599	0.076	9.85
4 d.	0.493	0.208	14.65	0.557	0.139	10.55
6 d.	—	—	—	0.513	0.183	12.55
	Commercial preservative products					
0 d.	0.628	0.047	8.43	0.614	0.057	10.09
2 d.	0.593	0.075	11.65	0.565	0.118	11.66
4 d.	0.534	0.134	16.01	0.490	0.198	19.03

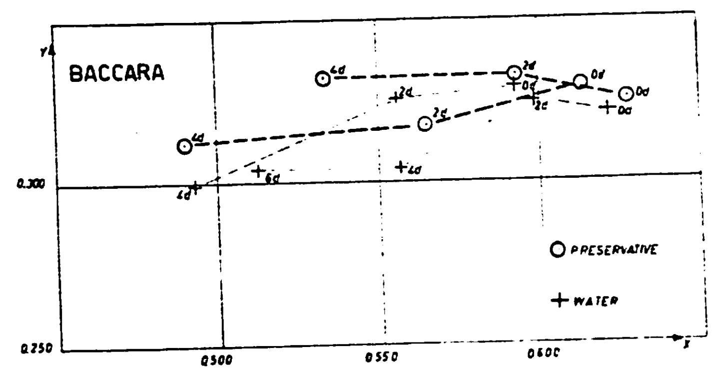

Fig. 1. Detail of the CIE chromaticity diagram representing the average chromaticity co-ordinates x and y of the petal colour of two series of cutted flowers of the rose variety 'Baccara' with or without the addition of preservatives.

The treatment with preservatives versus tap water results in rather similar changes in hue and saturation (expressed in the respective values x and z), as the colour is turning to purple. Nevertheless, with preservatives the lightness (Y) changes are more important than when no preservatives are applied : the increase is more than twice. These statements are illustrated by the following data :

x-value differences

tap water,	from 0 d. to 4 d. : series 1	= −0.100
	series 2	= −0.065
preservative products,	from 0 d. to 4 d. : series 1	= −0.094
	series 2	= −0.124

z-value differences

tap water,	from 0 d. to 4 d. : series 1	= +0.130
	series 2	= +0.082
preservative products,	from 0 d. to 4 d. : series 1	= +0.087
	series 2	= +0.141

Y-value differences

tap water,	from 0 d. to 4 d. : series 1	= +3.79
	series 2	= +2.39
preservative products,	from 0 d. to 4 d. : series 1	= +7.58
	series 2	= +8.94

The data for the carnation variety 'Red Scania' are given in table 2 and fig. 2. The colour changes are not varying in the same way as for 'Baccara'. The lightness (Y) can be decreasing, which means a darkening of the colour, or increasing, which means the colour becomes lighter. The x-value (red) is decreasing and the z-value (blue) increasing so that the colour becomes more purplish. The degree of these colour change is more important without than with a preservative. These statements are illustrated as follows :

TABLE 2

CIE-specifications for 'Red Scania' describing the flower colour after several days in tap water or with preservatives

	series 1			series 2		
days	x	z	Y	x	z	Y
	Tap water without preservatives					
0 d.	0.593	0.092	10.31	0.571	0.118	12.29
2 d.	0.531	0.154	12.41	0.546	0.152	11.27
4 d.	0.520	0.178	12.29	0.505	0.184	12.74
6 d.	0.481	0.224	16.68	0.424	0.281	10.16
	Commercial preservative products					
0 d.	0.564	0.123	13.17	0.545	0.147	12.79
2 d.	0.583	0.102	10.17	0.549	0.149	11.62
4 d.	0.508	0.216	10.62	0.529	0.167	12.25
6 d.	0.519	0.178	12.64	0.511	0.186	10.52

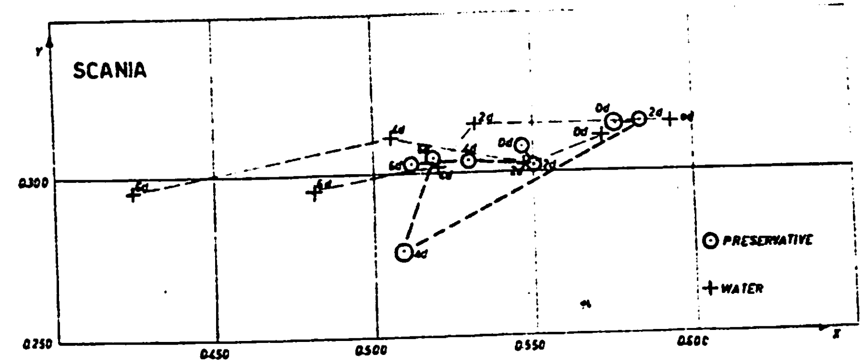

Fig. 2. Detail of the CIE chromaticity diagram representing the average chromaticity co-ordinates x and y of the petal colour of two series of cutted flowers of the carnation variety 'Red Scania' with or without the addition of preservatives.

x-value differences

tap water,	from 0 d. to 6 d. : series 1	= −0.112
	series 2	= −0.147
preservative products,	from 0 d. to 6 d. : series 1	= −0.045
	series 2	= −0.034

z-value differences

tap water,	from 0 d. to 6 d. : series 1	= +0.132
	series 2	= +0.163
preservative products,	from 0 d. to 6 d. : series 1	= +0.055
	series 2	= +0.039

Y-value differences

tap water,	from 0 d. to 6 d. : series 1	= +6.37
	series 2	= −2.13
preservative products,	from 0 d. to 6 d. : series 1	= −0.53
	series 2	= −2.27

In order to determine the quality of the cut flower a well-defined standard can be adopted. Independant of the development stage and apparent freshness of the flower it is possible to indicate that the flower has already reached a colour value corresponding to a declining of the quality. In this way deficient storage conditions could be detected in some cases before the product is marketed.

Some of the more recent objectives in our research was focused on working out an abridged and therefore a quicker way of measuring intended for colour research, based on physical measurements. This will create more possibilities for comparative colour research and for the grading of products.

To elaborate the abridged method, the principles of which are described by Mackinney & Little (1962), the carnation variety 'Red Scania' was chosen, it was particular suited as the reflection curve has a simple path. According to the usual method, the reflection has been recorded for 31 wavelengths, from 400 to 700 nm with an interval of 10 nm, followed by the calculation of the trichromatic specifications (CIE-system). From these extensive data 6 characteristic wavelengths (fig. 3) were selected in order to characterise the reflection curve of 'Scania' in this way that :

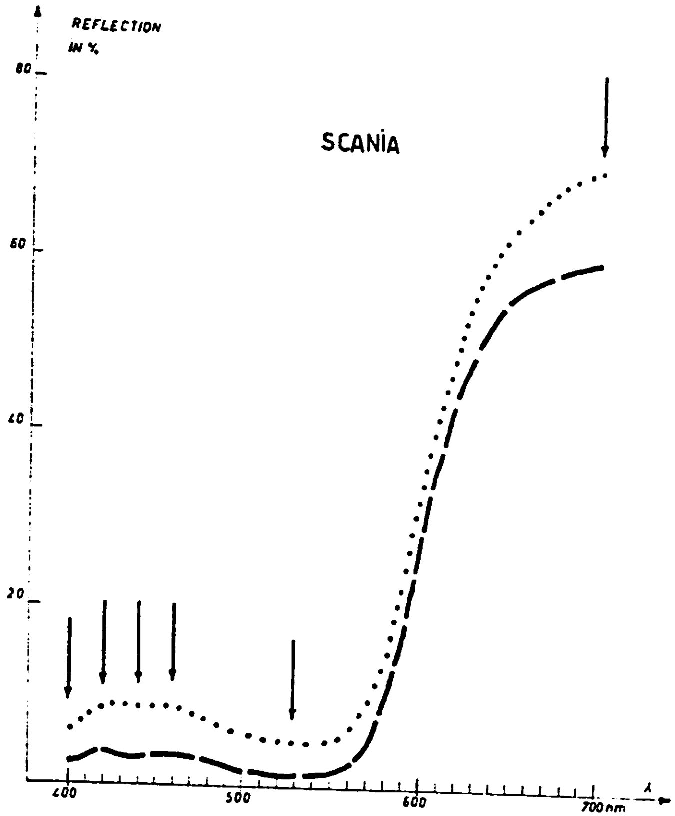

Fig. 3. Two reflection curves of the petals of the carnation variety 'Scania' indicating the characteristic wavelengths.

700 and 400 nm correspond to the highest and lowest wavelengths of the range measured,
530 nm gives a minimum of reflection,
460 nm gives a maximum of reflection,

440 nm gives a minimum of reflection,
420 nm gives a maximum of reflection.

Next the multiple regression of the different colour specifications (x, z, Y) on the reflection values for a limited number (maximum 3) of the 6 selected wavelengths were calculated (*) .The colour specification y was not involved in these calculations for in the case of 'Red Scania' these specification is not characteristic. From that great number of regression equations those were selected which gave the best approximation to the real values of the different colour specifications. They can be found in table 3. The calculation of the x, z and Y values becomes then rather simple.

Instead of measuring the reflection for 31 wavelengths, successive multiplications of the reflections with three constants at a time, followed by sommation to obtain the colour specifications requested, as was necessary with the extensive method (table 4), the reflection is now to be measured for only 4 wavelengths : 700, 530, 440 and 420 nm followed by the rather simple calculation using the equations (1), (2) and (3) of table 3.

TABLE 3

Method and equations to be used for calculating x, z and Y (abridged method) for the carnation variety 'Red Scania'

Measurement of reflection at wavelengths 700, 530, 440 and 420 nm.
Calculating of x, z, Y with :

$$x = 0.00264\ R_{700} - 0.0377\ R_{440} + 0.0206\ R_{420} - 0.4603 \quad (1)$$
multiple correlation coefficient : 0.947

$$z = -0.00306\ R_{700} - 0.0451\ R_{440} - 0.0265\ R_{420} - 0.2514 \quad (2)$$
multiple correlation coefficient : 0.929

$$Y = 0.19\ R_{700} - 0.45\ R_{530} + 0.96\ R_{420} - 4.072 \quad (3)$$
multiple correlation coefficient : 0.930

R_l : means the reflection at the wavelength indicated

The concurrence of the results between the usual method and the abridged one is rather good (see table 5). Table 5 is giving the data for several carnation flowers measured with the extensive method on the one hand and the abridged method on the other hand.

The equations (1), (2), (3) fit only for the carnation variety 'Scania'. It is evident that for other varieties or species new equations have to be looked up in order to calculate the colour specifications required.

(*) These calculations were accomplished with the aid of the "Bureau voor Biometrie" (Prof. Ir. Van Steenkiste, Prof. Dr. Ir. Rotti, Ir. Houthoofd)

TABLE 4

Calculation of the trichromatic colour specifications according to the extensive method (measurement at 31 wavelenghts)*

Wavelength in nm	Reflection in %	Tristimulus values		
		X	Y	Z
400	8.1	0.68	0.01	3.27
410	10.5	3.45	0.09	16.48
420	11.1	13.74	0.41	66.03
430	10.9	32.66	1.32	159.44
440	10.7	42.53	2.80	213.33
450	10.8	42.28	4.78	222.89
460	10.9	36.64	7.56	210.35
470	10.4	23.62	11.00	155.70
480	9.1	10.11	14.72	86.09
490	7.8	2.83	18.39	41.13
500	6.9	0.35	23.46	19.76
510	6.4	0.56	30.93	9.72
520	6.2	3.57	40.06	4.41
530	6.2	9.44	49.19	2.40
540	6.6	18.38	60.38	1.28
550	7.4	31.68	72.75	0.63
560	9.3	54.68	91.52	0.36
570	12.9	94.45	117.99	0.25
580	18.0	151.50	143.85	0.28
590	24.8	222.80	164.35	0.24
600	32.9	294.42	174.89	0.23
610	41.7	347.15	174.13	0.08
620	50.1	354.20	157.96	0.10
630	57.0	302.61	124.83	—
640	61.7	227.85	89.03	—
650	65.0	152.68	57.59	—
660	67.3	91.59	33.91	—
670	68.9	48.78	17.84	—
680	70.2	25.90	9.41	—
690	71.1	12.15	4.40	—
700	71.9	5.89	2.08	—
	sum/100 :	X = 26.5932	Y = 17.0175	Z = 12.1456

$$x = \frac{X}{X+Y+Z} = 0.477 \quad y = \frac{Y}{X+Y+Z} = 0.305$$

$$z = \frac{Z}{X+Y+Z} = 0.218$$

* These calculations are to be compared with the first line of table 5 (both results are concerning the same flower).

TABLE 5

Comparison between the extensive method and the abridged method for calculating x, z and Y

Measurement at 31 wavelengths			*Measurement at 4 wavelengths*		
x	*z*	*Y*	*x*	*z*	*Y*
0.477	0.218	17.02	0.475	0.220	17.46
0.499	0.194	14.77	0.510	0.184	14.94
0.424	0.295	12.55	0.418	0.289	12.47
0.570	0.119	12.24	0.575	0.112	12.50
0.589	0.097	9.28	0.589	0.098	9.87

Another example of the way colour differences can be detected and expressed is found with fruits of tomatoes (see table 6 and fig. 4). According to most of the scientific sources phosphorus can not be considered as a quality determining factor. Nevertheless, without going into details, phosphorus as a nutrient element influences slightly the colour of ripening tomatoes. This is illustrated by means of a few measurements taken from a recent research (Houthoofd, 1973). The tomatoes from the plants which received no phosphate are slightly darker red than the tomatoes coming from plants which did receive a phosphate fertilisation.

TABLE 6

CIE specifications for the skin colour of tomatoes in relation to the P-fertilisation of the plant

	x	y	Y
A: 0 g superphosphate/plant	0.490	0.330	9.38
B: 5 g superphosphate/plant	0.487	0.332	10.13
C: 15 g superphosphate/plant	0.482	0.331	10.08
D: 45 g superphosphate/plant	0.480	0.330	10.01

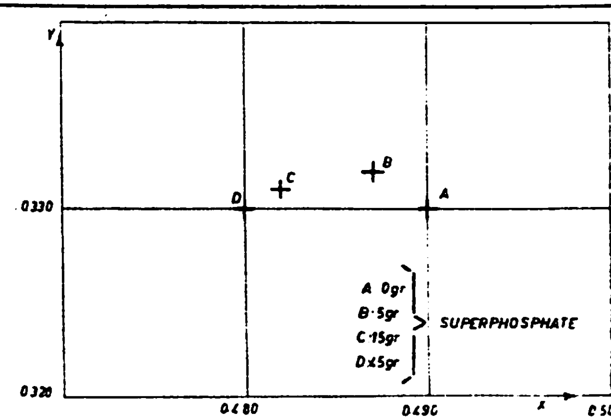

Fig. 4. Detail of the CIE chromaticity diagram representing the average chromaticity co-ordinates x and y of tomato fruits influenced by different P-doses.

Conclusion

In this paper it was not so much the aim to draw the attention to the utility of the physical method for colour description. The major object was to indicate in which way the circumstantiality of the usual methods, the accuracy of which is not denied, can be reduced without losing too much of the precision.

It still is necessary to dispose of a spectrophotometer with reflection attachment, but most of the laboratories are equiped with such an apparatus and the reflection attachment can easily be procured.

As for the traditional extensive method circumstantial calculations were required, so that for fast working a computer with reader is needed, it is sufficient with the abridged method to have a more simple calculator.

The time required for the recording of one coloured object is shortened drastically, so that more recordings can be effectuated in the same period of time. The petal, leaf or fruit to be measured remains only for a brief period in the apparatus, so that the object can stay fixed to the plant without serious damage. So consecutive measurements on the same object become possible.

BIBLIOGRAPHY

BOESMAN, G. (1964) : Fysische kleurmeting bij rozebloemen. *Verhandelingen van de Rijksfaculteit der Landbouwwetenschappen te Gent*, nr. 3,221 p.

BOESMAN, G. & FLAMEE, M. (1970) : Colour determination for horticultural purposes. *Mededelingen Faculteit Landbouwwetenschappen, Gent*, XXXV, nr. 1, 429-463

HOUTHOOFD. A. (1973) : Invloed van fosfaatbemesting op de produktie en de kwaliteit van de tomaat. (*Lycopersicum esculentum* Mill.) *Eindestudiewerk, Rijksuniversiteit Gent.*

MACKINNEY, G. & LITTLE, A. (1962) : Color of Foods, Avi Publishing Company, Westport, Connecticut, 308 p.

SAMENVATTING

Kwaliteitskontrole van tuinbouwprodukten door middel van de fysische kleurmeting in vergelijking met andere methoden van kleurbeoordeling

Enkele voorbeelden worden gegeven ten einde aan te tonen dat de fysische kleurmeting voor de kleurbeschrijving en de kleurbeoordeling van tuinbouwprodukten een bruikbare en exacte methode is.

De kleurveranderingen die optreden bij afgesneden bloemen van de anjervariëteit ‚Red Scania' en de rozevariëteit ‚Baccara', met of zonder toevoeging van een houdbaarheidsmiddel aan het vaaswater, worden besproken evenals de kleurbeoordeling van tomatevruchten afkomstig van planten bemest met verschillende fosfaatdossissen.

Ten einde de omslachtigheid van de gebruikelijke methode uit te schakelen, zonder een redelijke nauwkeurigheid te verliezen, werd een methode uitgewerkt om op een vereenvoudigde wijze de bloemkleur van de anjervariëteit 'Red Scania' te bepalen. Aldus is het mogelijk door het meten van de reflectie bij slechts 4 golflengten i.p.v. bij de traditionele 31 reflectiemetingen, de trichromatische waarden toch met een behoorlijke nauwkeurigheid te bepalen.

De fysische kleurmeting is dus ook toepasselijk op een eenvoudige en toch voldoende nauwkeurige wijze. Uiteraard moeten de hier vermelde methode en formules voor elk ander object aangepast worden.

RÉSUMÉ

Le controle de la qualité de produits horticoles par la colorimétrie physique en comparaison avec d'autres méthodes d'évaluation de la couleur

Quelques exemples sont donnés afin de démontrer que la colorimétrie physique est une méthode utilisable et exacte pour la détermination et la comparaison de couleurs de produits horticoles. Les changements de couleurs des fleurs coupées d'œillets 'Red Scania' et de roses 'Baccara' avec ou sans addition de produits de conservation, de même que le jugement de la couleur des fruits de tomates provenants de plantes ayant reçu des différentes doses de phosphate, sont discutés.

Afin d'éliminer le caractère circonstantié de la méthode traditionelle sans pour autant perdre une précision raisonnable, une méthode a été élaborée pour déterminer la couleur des fleurs d'œillets 'Red Scania'; de cette façon il est possible de calculer les valeurs trichromatiques par la mensuration de la réflection pour 4 longueurs d'ondes au lieu de 31.

La colorimétrie devient donc applicable d'une manière simple mais néanmoins suffisamment précise. La méthode et les formules proposées doivent évidemment être adaptées pour chaque objet.

ZUSAMMENFASSUNG

Qualitätsprüfung von Gartenbauprodukten mittels der physischen Farbmessung im Vergleich zu anderen Methoden von Farbbeurteilung

Einige Beispiele sind angeführt mit dem Ziel zu prüfen dass die physische Farbmessung eine verwendungsfähige und exakte Methode für die Farbbeschreibung und -beurteilung ist.

Die auftretenden Farbänderungen bei abgeschnittenen Blümen der Nelkenvarietät ‚Red Scania' und der Rosenvarietät ‚Baccara', mit oder ohne Zusatz von Haltbarkeitsmitteln im Wasser, wird besprochen, ebenso wie die Farbbeurteilung von Tomatenfruchten von Pflanzen mit verschiedener P-dosierung gedüngt.

Mit dem Ziel die Umständlichkeit der üblichen Methode aus dem Wege zu gehen, ohne eine annehmbare Genauigkeit zu verlieren, ist eine Methode um die Blütenfarbe von der Nelkenvarietät ‚Scania' auf einer vereinfachenden Weise zu bestimmen ausgeführt. So ist es möglich durch Reflexionsmessung bei 4 Wellenlängen anstatt 31, die Farbwertanteile zu bestimmen.

Die physische Farbmessung wird also anwendbar in einer einfachen und doch befriedigend genauen Weise. Selbstverständlich ist es erforderlich die Methode und die hier erwähnten Formeln für jedes weitere Objekt anzupassen.