RELATIONSHIP BETWEEN SENSORY EVALUATIONS AND NONDESTRUCTIVE OPTICAL MEASUREMENTS OF APPLE QUALITY[1]

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Accepted for Publication: September 12, 1983

ABSTRACT

A nondestructive optical method was studied for estimating the sensory quality of Golden Delicious and York Imperial apples. The coefficients of determination were significant for estimating sweetness of York Imperial, acidity of Golden Delicious and York Imperial, and crispness, hardness, toughness, and juiciness of Golden Delicious apples using optical measurements. The coefficients of determination were weakest with optical data at a single wavelength, intermediate with optical data compensated for fruit size and drift of instrument current, and strongest with multiple wavelength data. These analyses indicate that 30 to 50% of the variation in sensory attributes can be accounted for by factors affecting optical density of the fruit at specific wavelengths.

INTRODUCTION

A nondestructive optical density method has been described to estimate the quality of foods (Norris 1956). The method has been used to estimate the chlorophyll content of apples, and the chlorophyll content was shown to be correlated with the eating quality (Yeatman and Norris 1965). The chlorophyll content was shown to be correlated inversely with the soluble solids, and the latter related to the dessert quality of the apple (Olsen *et al.* 1967). Others have shown the chlorophyll content to vary inversely with soluble solids, sweetness, and flavor, and directly with tartness of apples (Aulenbach *et al.* 1972). In these studies, the quality was based on the chlorophyll content which was estimated by the nondestructive method.

This paper describes the use of optical density (OD) of a wide range of wavelengths for estimating sensory quality attributes of apples. Analysis was made with OD at

[1]Use of a company or product name by the Department does not imply approval or recommendation of the product to the exclusion of others which may also be suitable.

Journal of Food Quality 7 (1985) 219-226. *All Rights Reserved*

each single wavelength and with multiple wavelengths. Use of multiple wavelengths has been very effective for predicting quality of forage crops (Norris *et al.* 1956).

MATERIALS AND METHODS

Golden Delicious and York Imperial cultivars were selected for the study to represent apples that differ widely in color, flavor, and texture. To ensure variation in maturity and storage period, apples were harvested 3 times at weekly intervals and stored for durations of 0, 2.5, and 5 months. At each harvest, about 200 fruit were picked randomly from a commercial orchard and divided into 3 comparable lots for initial analysis and for analysis after 2.5 and 5 months storage in 0 °C air. Apples were stored in perforated plastic bags within fiberboard containers.

Freshly harvested or stored apples were held for 7 days at 20 °C before they were analyzed. Sixteen apples were selected from each lot and coded for maintaining identity throughout the analyses. The OD of each fruit was measured individually, and 8 of the 16 fruit were individually puncture tested (Magness-Taylor firmness probe mounted in an Instron Universal Testing Machine) and rated for sensory textural attributes, and the remaining 8 were individually rated for flavor sensory attributes and chemically analyzed for soluble solids and titratable acid. Thus, a total of 144 apples of each cultivar were tested for flavor and 144 for texture.

The optical densities were measured from 640 to 950 nm at 10 nm intervals with a high-intensity spectrophotometer (Massie and Norris 1975). To compensate for the variation in fruit size, the OD of each wavelength was divided by the cube-root of the mass and these values are noted as ODADJ. To compensate for variation in both fruit size and instrument current drift, the OD at 720 nm was subtracted from the OD at each of the other wavelengths, and these values are noted as ΔOD. Regression analyses were made with all 3 sets of data, i.e., OD, ODADJ, and ΔOD for the textural study, and only OD and ΔOD for the flavor study because fruit-mass data were not collected in the flavor study.

The 14 panelists for the sensory evaluations were trained in basic profile techniques as described elsewhere (Watada *et al.* 1980). Each individual fruit was rated for textural or flavor attributes by four panelists, and the average scores of the 4 panelists were used in the statistical analyses.

Firmness tests and analyses for soluble solids and titratable acids have been described elsewhere (Watada *et al.* 1980).

Individual fruit data were used for the correlation analyses between optical measurements and sensory and chemical data. The individual fruit data were also used for the stepwise multiple regression analyses for each of the 15 sensory attributes on the OD, ODADJ, or ΔOD for each cultivar. The maximum R^2 improvement program (SAS) was set with significance to enter and to remain at the 0.05 level and with a maximum of 5 steps.

Table 1. Sensory and objective evaluations of Golden Delicious and York Imperial apples.

Attribute	Golden Delicious			York Imperial		
	Average	Minimum	Maximum	Average	Minimum	Maximum
Sensory Evaluation[1]						
Flavor						
Sweetness	55	36	80	49	22	67
Acidity	32	5	76	45	14	77
Starchiness	22	2	57	25	2	59
Spiciness	21	3	44	22	6	54
Mustiness	11	2	47	13	1	47
Astringency	26	2	69	32	3	70
Texture						
Crispness	40	11	81	61	35	84
Hardness	28	4	75	50	24	88
Toughness	22	3	69	40	9	80
Mealiness	30	3	74	16	1	42
Juiciness	44	21	70	48	28	74
Objective Evaluation						
Firmness (newtons)	45	26	88	78	50	131
Soluble solids (%)	13.3	10.6	18.5	12.6	9.6	15.0
Titratable acids (%)	0.34	0.13	0.80	0.49	0.25	0.23

[1] Based on 100-point intensity scale.

RESULTS AND DISCUSSION

Sensory

The flavor profile panel selected sweetness, acidity, astringency, mustiness, floral-fruitiness, and starchiness as attributes associated with the flavor and taste of apples. Scores for all attributes, except floral-fruitiness of Golden Delicious and York Imperial and sweetness of York Imperial, changed significantly with storage (data not presented). Thus, a wide range of scores was available for the correlation analysis.

On a 100-point scale, the range between the minimum and maximum scores was 44 points or greater for all attributes except spiciness of Golden Delicious (Table 1). The range differed with attribute. For a given attribute, the width of ranges of the 2 cultivars were similar, except for acidity; the acidity range for York Imperial was about 90% of the range for Golden Delicious.

The average scores of a given attribute were similar for the 2 cultivars except sweetness and acidity. The average score for sweetness of Golden Delicious was higher than that of York Imperial and the reverse of this occurred with acidity.

The texture profile panel selected crispness, hardness, toughness, mealiness, and juiciness as attributes associated with texture of apples. Scores of all these attributes, except mealiness of York Imperial, changed significantly with storage (data not presented).

The range between the minimum and maximum scores was 46 points or higher for all attributes except mealiness of York Imperial (Table 1). As with flavor, the range differed with attribute; however, the ranges for a given textural attribute were not similar for the 2 cultivars. The average scores of the 2 cultivars differed by about 20 points for each attribute except juiciness. The average scores for crispness, hardness, and toughness were lower, and mealiness was higher for Golden Delicious than those for York Imperial.

Flavor Versus Optical Measurements

Of the flavor attributes, only acidity and sweetness of York Imperial and acidity of Golden Delicious were significantly correlated with the optical data (Table 2). The wavelengths correlating with acidity were not the same for the 2 cultivars. With York Imperial, the correlation occurred with wavelengths in the 650 to 690 nm range, whereas, with Golden Delicious, the correlation was with wavelengths in the 650 to 670 nm and 930 to 940 nm range. The coefficient of determination (R^2) was larger when the ΔOD were used rather than the OD value, which would be expected because variations in fruit size and instrument current drifts are compensated in the ΔOD values. Wavelengths correlating with sweetness of York Imperial were the same as those correlating with acidity when the analysis was made with OD. When the analysis was made with ΔOD, additional wavelengths in the 780 to 820 nm range and the 930 to 950 nm range were found to be correlated with sweetness.

In examining the best 5-wavelength combination for estimating sweetness, the wavelengths were not similar for both cultivars. With York Imperial, the selected wavelengths covered a broad spectrum of 640 to 930 nm; whereas, with Golden Delicious they were concentrated in the longer wavelength range of 870 to 940 nm. The R^2 was only 0.50 and 0.43, respectively. The best 5-wavelength combination for estimating sweetness of York Imperial covered a broad spectrum similar to that noted with acidity, but the wavelengths were slightly longer. No 5-wavelength combination was significant for estimating sweetness of Golden Delicious.

Constituents responsible for sensory acidity and affecting the OD appear to differ between the 2 cultivars. This is indicated by the fact that the 2 cultivars differed in the multiple wavelengths that were selected for both sensory acidity and titratable acids. The multiple wavelengths selected for estimating titratable acids were longer for Golden Delicious than for York Imperial with the R^2 being 0.46 and 0.53, respectively.

Table 2. Coefficient of determinations (R^2) for sensory flavor and chemical attributes versus optical density of apples. A range of R^2 values presented for a range of wavelengths.

Cultivar	Optical value	Wavelength (nm)	Acidity (R^2)	Sweetness (R^2)	Titratable acids (R^2)	Soluble solids (R^2)
York Imperial	OD[1]	650-690	.27-.34	.28-.31	---	---
	ΔOD[2]	660-670	.36-.41	.30-.32	---	---
	"	780-820	n.s.	.30-.32	---	---
	"	930-950	n.s.	.34-.36	---	---
	Stepwise[3] of ΔOD	640,700,790, 840,930	.50	---	---	---
	"	690,710,930, 940,950	--	.42	---	---
	"	660,690,730, 750,800	--	---	.53	---
	"	640,650,730, 760,920	--	---	---	.62
Golden Delicious	OD	650-670	.22-.23	n.s.	---	---
	"	930-940	.22-.23	n.s.	---	---
	ΔOD	640-820	.24-.28	n.s.	---	---
	"	940-950	.34	n.s.	---	---
	Stepwise of ΔOD	870,880,920, 930,940	.43	---	---	---
	"	5	---	n.s.	---	---
	"	790,800,810, 910,950	---	---	.46	---
	"	740,760,800, 910,950	---	---	---	.52

1 Optical density (OD) of whole intact fruit at a single wavelength within stated range.

2 OD at 720 nm subtracted from OD of each of other wavelengths.

3 Selection of 5 best wavelengths by stepwise regression analyses based on ΔOD (Maximum R^2 improvement, P to enter and P to stay set at 0.05).

Table 3. Coefficients of determinations (R^2) for sensory textural attributes versus optical density of apples. A range of R^2 values presented for a range of wavelengths.

Cultivar	Optical value	Wavelength (nm)	Crispness (R^2)	Toughness (R^2)	Juiciness (R^2)
Golden Delicious	OD[1]	650-680	.28-.34	.34-.38	.27-.30
	ODADJ[2]	650-680	.28-.34	.34-.37	.25-.28
	"	940-950	.35-.38	.31-.35	.30-.35
	ΔOD[3]	650-680	.34-.38	.38-.41	.30-.31
	"	940-950	.37	.37-.38	.35-.37
	Stepwise[4] of ΔOD	670,700,710, 920,940	.53	---	---
	"	670,690,930, 940,950	---	.48	---
	"	680,700,710, 730,950	---	---	.47
York Imperial	OD		n.s.	n.s.	n.s
	ODADJ		n.s.	n.s.	n.s.
	ΔOD		n.s.	n.s	n.s
	Stepwise		n.s.	n.s.	n.s.

1 Optical density (OD) of whole fruit.

2 OD divided by cube-root of mass.

3 OD at 720 nm subtracted from OD of each other wavelength.

4 Selection of 5 best λ by stepwise regresssion analysis based on ΔOD.

Texture Versus Optical Measurements

The textural attributes of only Golden Delicious correlated with the optical data and the attributes were limited to crispness, toughness, and juiciness (Table 3). Correlations were significant with OD at wavelengths in the 650 to 680 nm range. The correlation was found to be significant also with measurements at 940 and 950 nm when fruit was adjusted on the basis of mass (ODADJ) or optically (ΔOD). The coefficients of determination were slightly greater when using ΔOD values than OD or ODADJ values.

The best 5-wavelength combination for estimating crispness, toughness, or juiciness were all similar. This similarity is not surprising because these attributes correlated very highly with each other (data not shown). The selected wavelengths were in the 670 to 730 nm and 920 to 950 nm regions and the question arises as to the identity of textural factors which absorb at these wavelengths. The absorbing components responsible for the correlation between optical and textural data may not be textural factors, but factors closely associated with textural changes. For example, chlorophyll and carbohydrates change with texture and they absorb at the 660 and 930 nm regions, respectively. These and other components which change with texture and have absorption properties may be responsible for the correlations.

The lack of correlation between sweetness and optical measurements of Golden Delicious is puzzling. The average score for sweetness of Golden Delicious was higher than that of York Imperial and the widths of the range were similar for both cultivars. Carbohydrates absorb at the longer wavelengths of 910 to 950 nm (personal communication of Karl Norris, USDA, Beltsville, MD) so correlations were anticipated between sweetness and optical data at the longer wavelengths, providing absorption by other carbohydrates did not mask absorption by sugar. The lack of correlation probably was due to some factor such as acidity affecting the sensory response to sweetness. This is supported by the nonsignificant correlation between sweetness and soluble solids, the latter being an indicator of sugar content. Soluble solids did correlate with the optical data and in estimating the contents by multiple wavelengths, the coefficients of determination were 0.62 and 0.52, respectively, for York Imperial and Golden Delicious.

The lack of correlation between textural and optical measurements found in our study with York Imperial was also noted by Aulenbach *et al.* (1972) with Delicious apples. The textural characteristics of these 2 cultivars are similar in terms of intensity and minimal change with storage as indicated by firmness measurements (Watada *et al.* 1980). In our study, the coefficients of determination for firmness versus crispness and toughness of York Imperial were 0.40 and 0.43, respectively. Since these attributes can be estimated by the physical measurements of either cultivar and by the optical measurement of Golden Delicious, the lack of correlation between the optical and textural data of York Imperial suggests that its OD values associated with the textural attributes were affected by other absorbing constituents. This needs to be examined in future studies.

We conclude that the effectiveness of estimating the intensity of sensory attributes by the optical technique was improved by using multiple wavelengths. The selected wavelengths generally constituted a wide range of wavelengths and were not necessarily the same for a given attribute for the 2 cultivars. Only about 50% of the variations in sensory attributes can be accounted for by factors affecting optical density. This percentage needs to be increased substantially before the optical method can be used in commercial grading.

REFERENCES

AULENBACH, B. B., YEATMAN, J. N. and WORTHINGTON, J. T. 1972. Quality sorting of Red Delicious apples by light transmission. U.S.D.A. Marketing Research Report No. 936, pp. 21.

MASSIE, D. R. and NORRIS, K. H. 1975. A high-intensity spectrophotometer interfaced with a computer for food quality measurement. Transactions ASAE *18*(1), 173.

NORRIS, K. H. 1956. Measurement of quality in foods and agricultural commodities by physical methods. In *Proc. First Food Physics Symposium,* Inst. Food Technol. pp. 113–124.

NORRIS, K. H., BARNES, R. F., MOORE, J. E. and SHENK, J. S. 1976. Predicting forage quality by infrared reflectance spectroscopy. J. Animal Sci. *43*(4), 889–897.

OLSEN, K. L., SCHOMER, H. A. and BARTRAM, R. D. 1967. Segregation of Golden Delicious apples for quality by light transmission. Amer. Soc. Hort. Sci. Proc. *91*, 821–828.

WATADA, A. E., ABBOTT, J. A. and HARDENBURG, R. E. 1980. Sensory characteristics of apple fruit. J. Amer. Soc. Hort. Sci. *105*(3), 371–375.

YEATMAN, J. N. and NORRIS, K. H. 1965. Evaluating internal quality of apple with new automatic fruit sorter. Food Technol. *19*(3), 123–125.