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Nondestructive Spectrophotometric Determination of Dry Matter in Onions

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Abstract. **The techniques used in near infrared spectrophotometry for nondestructive analysis of agricultural products were applied to determine the percentage of dry matter (% DM) of intact onions (*Allium cepa* L). Transmittance data were recorded for the 700 nm to 1000 nm spectral region. Second derivative data processing was used with a stepwise multiple regression analysis to develop an equation to predict the % DM of individual onions. The correlation between optical data and % DM was 0.996. In a 2nd and completely independent experiment, we obtained equivalent results demonstrating the repeatability of the method. This repeatability was demonstrated even further through the satisfactory field testing of a portable instrument.**

Onions are a major international vegetable crop whose culture and use are not limited by a narrow climatic range or specific nationality. Of the annual United States production, more than 250,000 MT, or 15% of the total crop, are processed by dehydration (8,9). Since typical onion cultivars contain about 90% moisture, most of which is lost during drying, there has been considerable interest in increasing the percentage of dry matter (% DM) genetically in cultivars used for commercial dehydration. An increase would allow raw product costs to remain constant while increasing the quantity of the processed product.

Mann and Hoyle (11) established that soluble solids (SS), determined by measuring the refractive index of juice expressed from the outer fleshy scales, could be used to predict % DM of onions for breeding purposes. This procedure is time consuming, and removal of the outer fleshy scales leaves the bulb susceptible to spoilage. A rapid nondestructive means of screening onions for % DM would increase greatly the number of genetic crosses that could be surveyed, thus increasing the selection pressure for dry matter.

Whereas there are a variety of nondestructive tests which might be used (e.g., mechanical, thermal, electrical, or radiant energy), optical measurements are particularly suitable for viable intact samples because they require low energy, thereby minimizing tissue damage. Researchers have studied the optical properties of various agricultural products and have established correlations between optical characteristics and other quality-related properties of the products. These applications of nondestructive optical techniques for measuring surface and internal quality include assessment of ripeness and maturity (5, 12) and defects such as bruised tissue (6), water core in apples (3) and hollow heart in potatoes (1).

Turley (16) applied this technology in determing the % DM of onions. Her work established: a) a satisfactory geometrical arrangement (Fig. 1); the significant wavelength region (800 nm to 1000 nm) to use for predicting % DM; c) that improved results were obtained by averaging 2 data sets obtained with the onion in 2 positions (before and after rotating 180° about the basal-apical axis); d) that a linear regression analysis was applicable; and e) that variation in the physical characteristics of the onions, i.e., size, shape, weight, and specific gravity, did not significantly affect the measurement of % DM. Based on those results and using the same instrumentation, additional experiments were undertaken to develop the technique to a point suitable for practical application.

Materials and Methods

Instrumentation. A biological spectrophotometer (Biospect) (4), designed for conveniently changing the source-sample-detector geometry, was used to generate the spectral data. The instrument has a 6.0-nm bandpass and has radiant power in excess of 3 mw over the wavelength range from 500nm to 1200 nm. Procedures similar to those in a previous study of papaya maturity (2) were used. A crucial aspect of this work is the interaction of the light source, sample, and the detectors (Fig. 1). The detector outputs (currents) are added and amplified so that the input to the data acquisition system varies from 0 to 10 V. The Biospect is computer-controlled, and the data are recorded in digital form at 0.5-nm wavelength increments.

A Teflon rod (7.6 cm diameter × 10.2 cm) was machined with a spherical surface on one end to serve as a standard and fit the detector assembly in the same manner as the onions. This standard has low absorption, and the light scattering characteristics are similar to those of the onion. A reference curve was obtained with the Teflon standard, so the ratio of the data for an onion to the data for the standard is a relative transmittance (T) spectrum for the onion. These data were converted into log 1/T or optical density (OD) and stored for later analysis. Based upon the work of Turley, 2 independent measurements were made on each onion. These measurements were averaged to obtain a single prediction of % DM for each onion. This procedure was followed for all experiments described in this report.

An abridged portable instrument (the onion meter), using tilting filter technology (15), combined with a small computer, was developed in this laboratory to provide the capability of determining % DM nondestructively on a large number of on-

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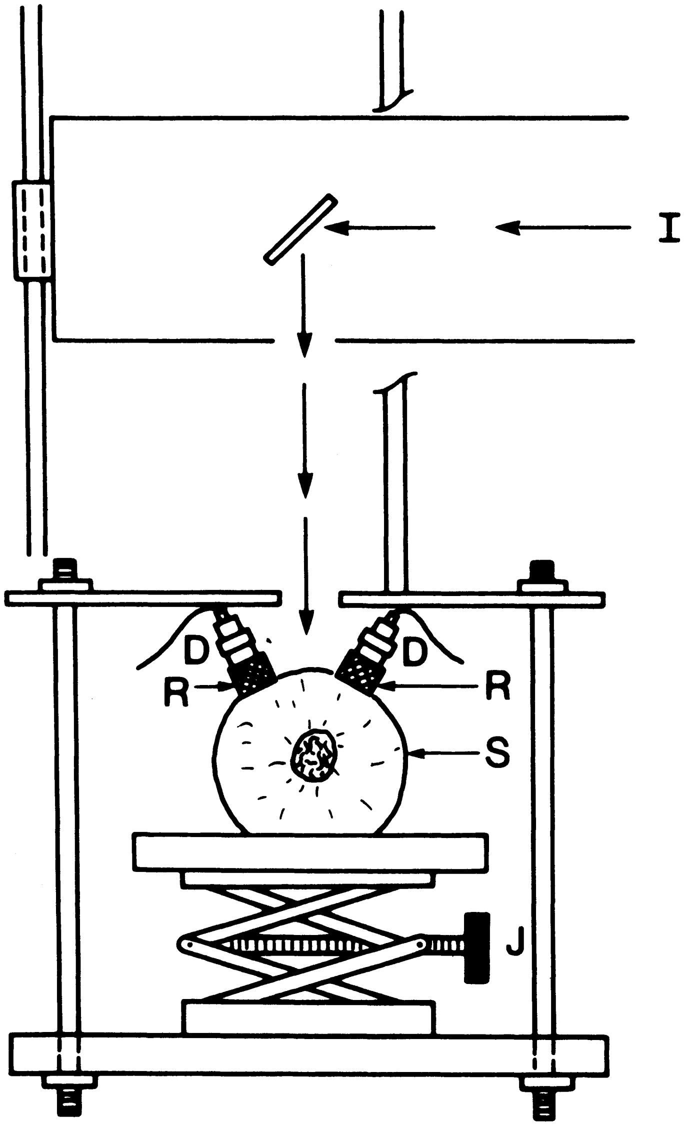

Fig. 1 The source(I)-sample(S)-detector(D) geometry used for obtaining spectrophotometric data with the Biospect. The onions were positioned with the basal-apical axis horizontal. The detectors were positioned to fit the general contour of the onions and were held rigidly after adjustment. The bulb was raised with the scissors jack (J) to contact the rubber cushions (R) that provide a light-tight seal. Thus, the only radiation incident on the detectors is that which has been transmitted through the onion flesh. The distance from the illuminated area to the point of measurement is constant.

ions and to facilitate field testing. The onion meter used the same geometry as shown in Fig. 1. In order to accommodate a wide range of onion sizes and shapes, however, the detectors were mounted on a hinged assembly. This instrument was calibrated for % DM with the same procedure as was used with the Biospect. After calibration, the % DM could be determined for a single onion in about 12 sec.

Experimental plans. Experiment 1 served to develop a precise relation between the spectral and chemical data, and to test that relationship. Twenty onions were selected from each of 3 locations (Georgia, Texas, and California) to provide a wide range of dry matter levels. The onions were divided into 2 lots of 30 with equal numbers from each location. One lot was used for calibration, and the other was used to test the prediction.

Experiment 2 involved the development of an instrument (the onion meter) suitable for field use, in which the % DM could be determined for an individual onion in a few seconds. Over 200 'Southport White Globe' onions were obtained for Expt. 2. The onions were sorted to provide minimum size variation and to eliminate defects. Spectral data were obtained on 120 of the selected onions with the Biospect. Utilizing the calibration equation developed in Expt. 2, the % DM for each was predicted. The onions were divided into 2 groups in which the size and the % DM ranges had similar distributions. The final number of onions in each group was 50. One group of onions was used to calibrate the onion meter. The other group of onions was dried to obtain data to verify the calibration.

For Expt. 3, the onion meter was transported to a field location where a large number of onions of different cultivars and % DM was available. Onions from 5 breeding lines of 'Southport White Globe' in addition to red and yellow onions were included in the experiment. These onions were separated into dry matter groups, using a 2%-DM increment for each group. The % DM ranged from 10% to 25% for these samples. Two onions were taken at random from each % DM group for each cultivar or breeding line, and the spectral data were recorded with the onion meter. These onions (118) were dried, and the data for even-numbered bulbs were used to recalibrate the onion meter. The new calibration was used to predict the % DM for the odd-numbered bulbs.

Sources of onions. About 90% of the onions used in this work were 'Southport White Globe' produced in California. Onions from Georgia and Texas (cultivars unknown) were included to increase the range of % DM, and, in addition, numbered breeding lines were obtained from Gilroy Foods in Gilroy, Calif.

Data processing. Data and regression computations of experimental results were processed with a single computer program. This approach provides for optimizing the data processing computations, which are primarily 2nd derivatives. Numerical computations of 1st derivatives may be expressed as $(\Delta OD)/\Delta\lambda$ where $\Delta\lambda$ is a fixed wavelength increment.

The notation can be simplified by substituting the letters A, B, and C for the OD at 3 successive wavelengths. Using λ for the wavelength of B, the wavelength for A is $\lambda - \Delta\lambda$ and for C, $\lambda + \Delta\lambda$. Then, the 1st derivative is $B - A$, and the 2nd derivative is $(C - B) - (B - A)$ which reduces to $A + C - 2B$. In addition, data averaging is incorporated in the computation of derivatives. That is, data from several adjacent wavelengths (points to sum) are combined for data averaging to determine the values of A, B, and C. The final computation is a single term regression equation that includes the ratio of 2 2nd derivatives (13):

$$\%\ DM = K_0 + K_1 \left(\frac{A_2 + C_2 - 2B_2}{A_1 + C_1 - 2B_1}\right) \qquad [1]$$

There are 5 wavelength-related parameters and 2 regression constants that must be defined numerically in the calibration procedures. The 5 wavelength-related parameters are: 1) wavelength for B_1; 2) wavelength for B_2; 3) wavelength difference (gap) between A_1 and B_1 and between B_1 and C_1; 4) wavelength difference between A_2 and B_2 and between B_2 and C_2; and 5) points to sum: this is the same for A_1 through C_2. The 2 regression constants are: K_0) regression constant (intercept); and K_1) regression constant (slope).

A single-term stepwise regression analysis was used to develop the equation for predicting % DM. The program "steps" through the wavelength range being studied and identifies the wavelength that gives the highest correlation coefficient, then increments one of the other parameters of the computation and repeats the regression analysis to optimize that parameter. The process is repeated until all of the parameters are optimized. This procedure is referred to as instrument calibration.

The error associated with calibrating the instrument is defined by the SE of calibration (SEC):

$$SEC = \sqrt{\frac{\Sigma(\hat{Y} - Y)^2}{N - 2}} \qquad [2]$$

where Y = the % DM determined by freeze drying the sample; $\hat{Y}$ = the predicted % DM based on optical measurements and computed with the regression equation that was developed with the same data; and N = number of samples.

Another important indicator of performance is the SE of prediction (SEP). In this case, a 2nd group of samples is analyzed, and, using the regression equation developed with the data from the 1st group of samples, % DM values are predicted. Those data are used with Equation 2 to compute SEP.

Chemical analysis. Dry matter was determined by freeze drying and by oven drying at 70°C for 5 hrs in a forced draft oven. Nitrogen was determined by the Kjeldahl method as described in the Official Methods of Analysis of the A.O.A.C. (14). Soluble solids were determined refractometrically on a solution expressed from the sample with a garlic press. Simple sugars of fresh onion samples were extracted with 80% ethanol in a Soxhlet apparatus. The solvent was removed in a rotary evaporator, and the concentrated extract was reconstituted to the appropriate concentration with distilled water. The final solution was centrifuged and filtered prior to analysis for glucose, fructose, sucrose, and oligosaccharides using a carbohydrate analytical column in a high performance liquid chromatography system. Hydrolysis of oligosaccharides was accomplished by suspending the sample in 0.02 M HC1 and heating for one hr at 100°C. The residue from the Soxhlet extraction after oven-drying to a constant weight represented the alcohol-insoluble solids.

Solution spectra. The spectra of optically clear solutions were obtained with a spectrophotometer employing a Cary monochromator. The 1st sample consisted of onion juice which was centrifuged to remove light scattering materials. A portion of the juice was dialyzed to remove the sugars, and the liquid remaining inside the dialysis tubing was concentrated to the original volume for use as the reference. The onion juice also was analyzed for specific sugars, and an equivalent solution was prepared using pure sugars and distilled water. A sugar solution spectrum was obtained using distilled water for the reference. The absorption due to the sugars was relatively low, so a long pathlength (up to 5 cm) was used to obtain low noise spectra, and the data were adjusted to a 1.0-cm pathlength.

Results and Discussion

Spectral data. An example of an OD spectrum with a 2nd derivative spectrum obtained with a typical onion is illustrated in Fig. 2. The OD spectrum of an onion is a function of light scattering and absorption. The variation in OD at a wavelength of low absorption is largely due to light scattering, whereas the shape of the curve is related to absorption. Derivative computations are sensitive to curve shape but less responsive to the variation in OD values at a low absorbing wavelength. This response is illustrated in Fig. 2 which indicates the variation in values of OD and d^2OD at 900 nm, a low-absorbing wavelength.

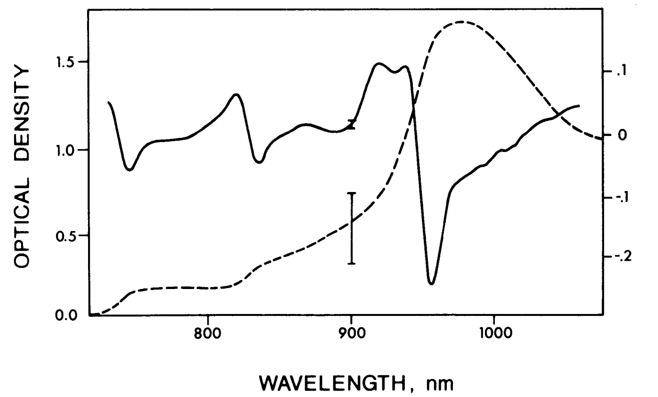

Fig. 2 Optical density (broken line) and 2nd derivative spectra (solid line) of a white onion recorded with the geometry illustrated in Fig. 1. The data consist of 900 discrete OD measurements. The 2nd derivative data processing involves several data for each computation to permit signal averaging. For this curve, 75 points were used in the computation so the 1st valid computation occurs at the 38th pt. The vertical lines at 900 nm show the range in values for the OD and the d^2OD curves for 30 onions.

Expt. 1. One lot of 30 onions was used to develop a regression equation for calibration of the instrument in respect to % DM. The SEC was 0.53 and the correlation coefficient was −0.9957. The 2nd lot of 30 onions was used to test the relation by predicting the % DM. A scatter plot of actual % DM vs. predicted % DM, where the predicted values were computed with the above calibration regression equation, is shown in Fig. 3. If the relationship were perfect, all values would fall on a 45° line. Deviations from that line can be interpreted as a measure of the accuracy of the method. In this case the SEP is 0.79. In Fig. 3, there is an apparent change in the slope of the best line through the prediction data. One explanation of this change could be inherent variations in the sample. However, we are confident that the sampling procedure was reliable since our previous experience with this approach has led us to accept a sample size of 30 as statistically sound. We attribute the change in the slope to instrument drift. The shape of the spectral curve in the region of interest must be repeatable to within 0.00015 OD in order to achieve the accuracy being reported. These measurements were made at the borderline of this capability.

Recognizing that the scatter plot is concentrated at the extremes, one could not conclude from these data that the relationship is necessarily linear. Previous work by Turley (16), however, established this relationship as linear. Our efforts here are to improve the precision of the measurement.

Expt. 2. Independent regression equations were developed for Expt. 1 and 2. Comparison of these equations is an important means of evaluating this method for predicting % DM of onions. These results are shown in Table 1. The equations for predicting % DM were very reproducible as evidenced by the similarity of the wavelengths, regression constants, *r*, and SEC. The soluble solids (SS) data are included in this work, since that analysis is one of the primary measurements used by other researchers to evaluate onion quality. Since in our work the repeatability of the constants in the equations for predicting SS was not as good as for % DM, SS was not used further in these experiments. Data obtained with freeze drying consistently gave better results, so oven drying data were not used.

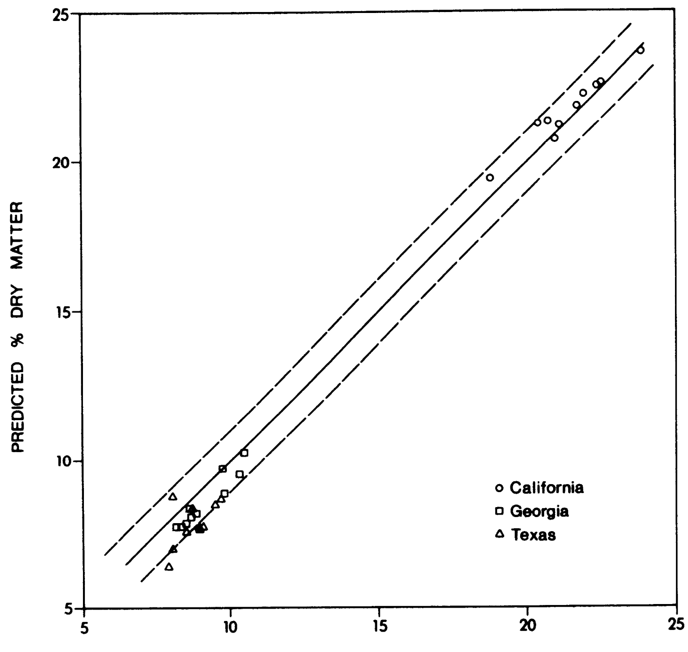

Fig. 3 The results of regression computations with spectrophotometric data to predict the % dry matter of intact onions. Thirty onions were used to establish the regression line and the 95% confidence limits, this determines the instrument calibration. The plotted points are the result of using the regression equation to predict the % dry matter for an independent group of 30 onions. The onions were produced in 3 different geographic areas as defined by the 3 symbols. All onions weighed less than 200 g.

A scatter plot of the data for Expt. 2 is shown in Fig. 4. The onions in this experiment varied in weight from 127 g to 380 g. Analysis of onion weights and the distribution of data in Fig. 4 indicated that the small onions had more error in predicted % DM than the large bulbs. As a result, the onions weighing less than 200 g were identified and the SEC was computed with and without the small onions. That computation gave SEC = 0.42 without the small onions and with all onions, 0.71. The size effect appeared to be an instrument factor. The rubber cushions shown in Fig. 1 must contact the onion to prohibit ambient light from reaching the detectors. Since the detectors were mounted rigidly, a large variation in onion size and shape can result in situations where ambient light is not completely eliminated. The results of Expt. 1 provide evidence that the error in predicted % DM is not related to onion size alone. All of the onions in Expt. 1 were less than 200 g, yet the SEC was 0.53 which is comparable to the results of Expt. 2 using only the large onions.

The results, given in Table 1 for Expt. 2, are based on the large onions which ranged in size from 200 g to 380 g. Also, results of this regression analysis indicate that a linear equation is suitable for predicting % DM.

The onion meter was calibrated with onions for which the % DM was known (predicted with the Biospect), so the correlation could be completed quickly and repeated if instrument modifications were necessary. The correlation coefficient for the calibration of the onion meter was 0.9715.

Even though the onion meter used a system with movable detectors, it was still necessary to limit the size range of the onions to 6.8 cm to 8.4 cm for reliable operation. A plastic sizing board was constructed to facilitate onion sizing. In practice, relatively few onions were eliminated because of size.

Expt. 3. This experiment was limited to onion meter data obtained at a field location. One hundred eighteen onions were taken from 7 sources to provide as wide a range of % DM as possible. The predicted % DM for 2 of these 118 onions differed from the actual values by an amount that should occur less frequently than once in 10,000, so data for those 2 onions were eliminated from the analysis. As a result, the number of onions in the prediction set was 57.

The results of the calibration yielded : r = 0.9713 and SEC = 0.9335. This is comparable to the initial calibration of the onion meter. The results obtained with the prediction set are shown in Table 2. The numbered breeding lines generally have a high SEP and included several onions having flat sides, probably due to a high plant density during the growing season. Those onions that deviated appreciably from a circular cross section were difficult to fit the detector assembly and were subject to errors in the optical measurements.

The mean shown in Table 2 indicates a bias and should have a value near zero. For onion groups where the bias is large, improved accuracy could be obtained by developing a special calibration for that group. Inclusion of a number of cultivars in a calibration will tend to decrease the accuracy.

The SEP for this experiment was 0.9722, about twice the value for SEC obtained with the Biospect in Expt. 1 and 2. Part of this increase in error is related to Expt. 3 being a field experiment. Another factor is the instrument error. To evaluate this error, we computed the SD for 10 measurements of % DM taken on a single bulb without disturbing the bulb. The errors for the 2 instruments were: Biospect, 0.129, and Onion Meter, 0.581.

Overall, these results indicated that the onion meter needed

Table 1. Regression equation data developed with the Biospect.

Experiment no.	Measured variable	Wavelength (nm) Num	Den	Regression N^z	K_o^y	K_1	r^x	SEC^w	SEP^v
I	% DM	908	872	30	34.7	−15.2	−.9957	0.53	0.79
	SS	878	900	30	0.58	21.6	.9702	1.26	3.41
II	% DM	906	868	29	34.7	−17.5	−.9958	0.42	
	SS	908	897	29	54.5	−131.0	−.9849	0.70	

[z]N = Number of samples used in the regression analysis.
[y]K_o and K_1 = regression coefficients as defined in equation 1 in text.
[x]r = linear correlation coefficient.
[w]SEC = SE of calibration (equation 2).
[v]SEP = SE of prediction (equation 2).

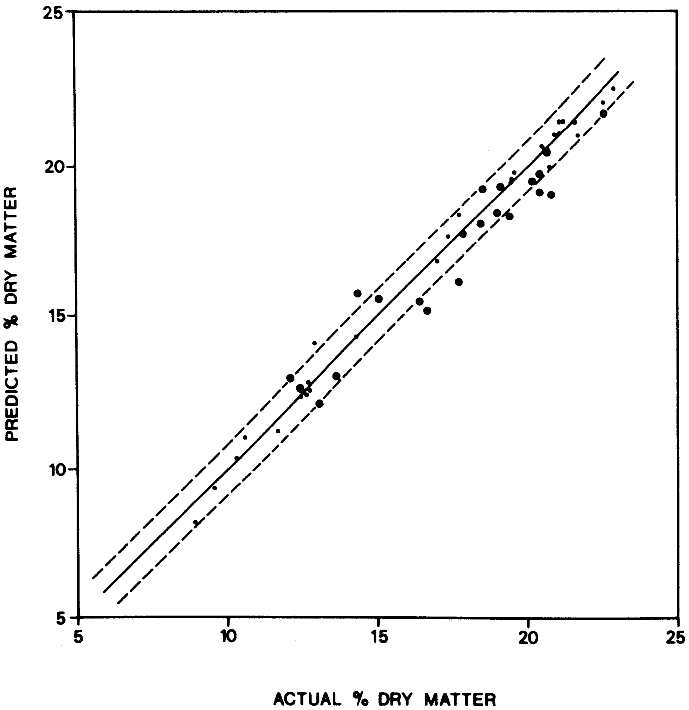

Fig. 4. Regression analysis (Biospect data) for Expt. 2. The circled points are the values for onions that weighed less than 200 g (21 onions). The regression computations involved only the data for 29 onions ranging in weight from 200 g to 380 g. The SEC was 0.42 for the 29 large onions. When all onions were included the SEC was 0.71.

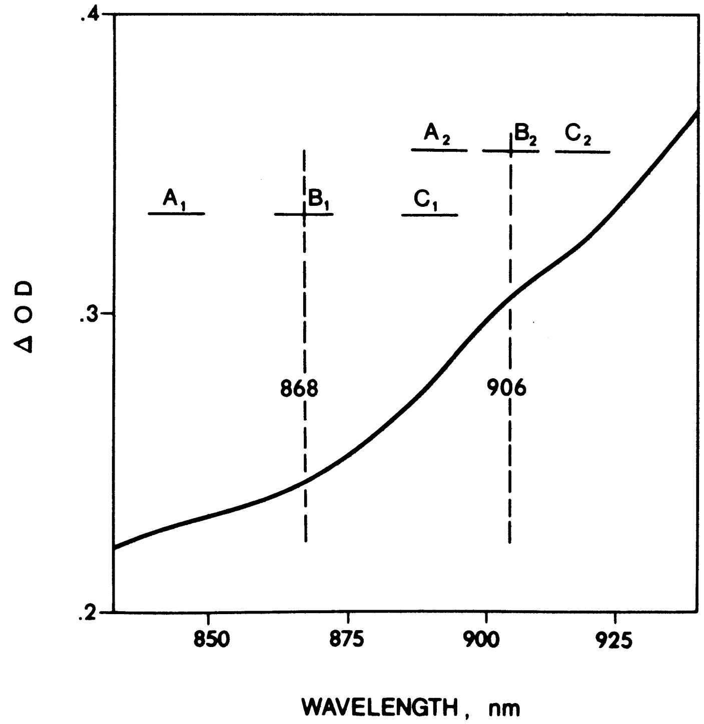

Fig. 5. A curve computed by substracting the spectral data for a low % DM onion from data for a high % DM onion. The letters refer to the data used to compute the ratio of 2 2nd derivatives. The horizontal lines under the letters indicate the amount of data summed to provide signal averaging for each quantity A_1 to C_2. The wavelengths for B_1 and B_2 are for predicting % DM in Expt. 2.

Table 2. Statistical results for predicting % DM for 7 onion groups with the onion meter.

Identification of onion group	Mean[z] deviation	N	SEP[y]
312[x]	−0.84	4	1.25
804	−0.28	17	1.21
1404	0.34	8	0.72
1405	0.86	6	1.73
1509	0.54	10	0.98
Red	0.43	7	0.88
Yellow	0.90	5	0.29
Overall	0.23	57	0.97

[z]Mean is the average difference between the actual % DM and the predicted % DM.
[y]SE of prediction.
[x]Numbers indicate breeding lines of the 'Southport White Globe' cultivar.

improvement in 2 areas. First, limitation in the range of sizes that can be measured, and 2nd, the repeatability of the measurement. These factors were resolved in the development of a commercially available instrument.

Spectra and composition

The OD spectrum in Fig. 2 does not show an absorption band that corresponds with the wavelengths that are used in the regression equation. In order to display the spectrum at higher sensitivity, it was necessary to compute a difference curve, which is the difference in OD between spectral data for an onion of high % DM and data for a low % DM onion. The resulting curve (Fig. 5) could be displayed at sufficiently high sensitivity so that a weak absorption band appears at the same wavelength used for the numerator of the regression equation. The spectral definition of the data used to compute the % DM with Equation 1 also is illustrated in Fig. 5.

Table 3. Chemical composition of low ('Granex') and high ('Creole') dry matter onions.

Analysis (% fresh wt)	'Granex'	'Creole'
Dry matter	11.10	19.14
Alcohol insoluble solids	1.74	4.50
Protein - total	0.88	1.53
Protein - soluble	0.66	1.04
Protein - insoluble	0.22	0.49
Lipids	0.39	1.34
Ash	0.31	0.53
Carbohydrate by difference	9.52	15.74

In order to obtain an understanding of how specific constituent concentrations vary with different levels of dry matter in onions, we examined the composition of low dry matter ('Granex') and high dry matter ('Creole') types of onions. The compositions are presented in Table 3. If the protein, lipid, and ash concentrations are determined directly, then the sum of these values can be subtracted from the dry matter value to derive a value termed "carbohydrates by difference." Carbohydrates, which include fiber, starch, and sugar, account for 85.8% and 82.2% of the dry matter in 'Granex' and 'Creole' onions, respectively. These values are in agreement with values reported by Darbyshire and Henry (7), who also reported an association of fructans with high percentage dry weights in onions. Using

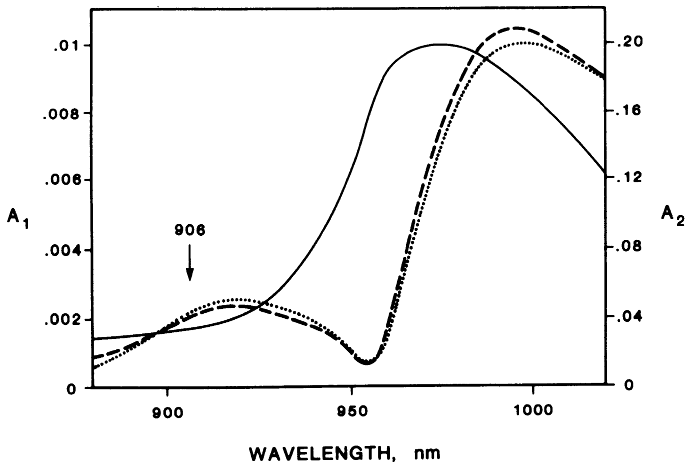

Fig. 6. Spectra of onion juice (dotted line) with dialyzed juice for a reference, sugar solution (dashed line) with distilled water for the reference and water (solid line) with an empty cell for the reference. The absorbance scale A_1 applies to the onion juice and sugar solution; A_2 applies to the water spectra. The specified wavelength (906) is the wavelength where the best prediction of % DM was obtained as defined in Table 2. The data are for 1.0 cm-pathlength.

high performance liquid chromatography (HPLC), we were able to demonstrate the presence of 9 peaks in the chromatogram of 'Creole' onion extracts. When the extract was subjected to mild hydrolysis, the oligosaccharide peaks disappeared with a consequent increase in the fructose peak size. These fructans appear to account for about 50% of the soluble carbohydrates in 'Creole' and 10% in 'Granex' onions. The carbohydrates in low and high dry matter onions account for at least 82% of the dry matter and are primarily in the form of fructans, fructose, glucose, sucrose, and fiber.

To establish the association between the absorption in the vicinity of 906 nm and carbohydrates, we recorded solution spectra for raw onion juice and an equivalent solution of simple sugars. The spectra for these 2 solutions are shown in Fig. 6. These results show clearly that the absorption in the vicinity of 906 nm is associated with carbohydrates. The maximum absorption occurs at 918 nm. The reason the best results are obtained at a shorter wavelength is probably due to the effect of other substances in the onions. Inspection of the spectra in Fig. 6 indicates that the % DM could be determined by spectral measurements in the 950-nm to 1020-nm region, based on the absorption due to either water or carbohydrates. The results do not support such an observation. This lack of agreement may be due to the detector outputs being reduced, by a factor of about 10, relative to 906 nm, so that signal noise and stray light would likely give rise to serious errors in predicting % DM.

Onion meter utilization

In addition to the use of the onion meter for determining dry matter in segregating populations in an onion breeding program, we see a number of other potential applications of this concept. The basic unit can be incorporated into an automated system which could be used in a standard grading system for onions. Foskett and Peterson (10) demonstrated that with 60 varieties and breeding lines in which dry matter ranged from 8% to 13%, the high dry matter onions tended to store better than low dry matter onions. The onion meter could be of value in making separations of this type. It is conceivable that a meter of this type could be used in quality control during the processing of onions. We believe the concept of the onion meter can be extended to other products. Work involving modification of the onion meter concept is in progress and hopefully will lead to the capability of nondestructively determining proteins, lipids, and carbohydrates in fruit and fruit products.

Summary

The application of spectrophotometric techniques to predictions of % DM in onions, using empirical procedures, resulted in correlations above 0.995. This is a very high correlation, considering the variables that are likely to be present in intact onions. Such a high correlation implies more than a casual relationship between the optical measurements and the constituents that make up the dry matter of the onion. It was shown that carbohydrates are the primary constituents of the dry matter. In addition, the regression equation is based on transmittance data obtained at 906 nm, which is in the vicinity of an absorption band that is associated with carbohydrates. On the basis of these results, we conclude that there is direct association between the results obtained with the regression equation that was developed to predict dry matter of onions and the concentration of carbohydrates in the onions, the major constituent of the dry matter.

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Influence of Cultivar and Flower Thinning within the Inflorescence on Competition among Olive Fruit

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Abstract. **Experiments with heavily-flowering olive trees showed only one period of abscission of flowers and fruit in the 5–6 weeks following full bloom. This abscission of flowers and fruit is responsible for the small percentage of fruit retained to maturity. Most of the fruit drop was concomitant with initial fruit growth for all cultivars. There were no differences in the number of fruit per inflorescence among cultivars, but the percentage of inflorescences with fruit at harvest was related negatively to final fruit size for each cultivar. Thinning of perfect flowers within the inflorescence did not affect fruit set at the inflorescence level; thus, the inflorescence behaved as a unit of fruitfulness. Competition among fruits played a significant role in fruit set. Initial setting induced by pollination and fertilization is counteracted early by fruit abscission originated by competition among fruit. In light of this early abscission, the use of fruit set to indicate response to pollination in previous experiments is questioned.**

Olive blooms strongly in "on" years, but only a small number of flowers are able to set fruit that remain until harvest. Griggs et al. (7) have defined a good crop as 1% of the original flowers setting fruit and remaining until harvest. Rallo et al. (16) studied the seasonal changes of fruitfulness in olive and stated that reduction in fruit number takes place within the first 5–6 weeks after full bloom, suggesting that competition among fruit, triggered by fertilization and early fruit growth, is mainly responsible for fruit abscission.

The purpose of this study was to evaluate cultivar differences and the influence of flower thinning within the inflorescence on fruit setting in order to assess the importance of competition in olive fruitfulness.

Materials and Methods

Expt. 1. Seasonal pattern of fruit set and development in 6 cultivars. Number of inflorescences, flowers, and fruit, as well as shoot growth were determined from bloom until harvest in 'Arbequina', 'Picual', 'Manzanillo', 'Lechin', 'Hojiblanca', and 'Cornicabra'. These cultivars are adapted to distinct growing areas in Spain, and differ in both fruit size and fertility. Five-year-old trees growing in a varietal plot at the Instituto Nacional de Investigaciones Agrarias farm in Alameda del Obispo, Córdoba, were chosen. The trees were trained and irrigated following locally approved practices, and continuous treatment was done from bloom to harvest to prevent *Prays oleae* Bern.

Four heavily flowering trees for each cultivar, and 10 uniformly distributed fruitful shoots per tree were selected and tagged in spring, 1980. Numbers of inflorescences and flowers per inflorescence were counted per shoot, just before full bloom (FB; the time when more than 50% of the flowers had opened in at least 75% of the inflorescences). Number of fertile inflorescences, perfect flowers, and fruit per inflorescence were determined at 5, 12, 15, 21, 26, 36, and 48 days after FB. Inflorescences were considered fertile when they bore at least one perfect flower or one persisting fruit. Perfect flowers were first determined at FB + 5, at which time petal-fall occured. Length and number of nodes, and number of leaves per fruitful shoot (corresponding to 1979 growth), were determined during the spring of 1980. Vegetative growth of 1980 was similarly determined 7, 17, and 57 days after FB, and at harvest. Average weights for 20 fruit per tree were determined at 3, 6, 9, 12, 15, 20, and 30 days after FB, and at harvest.

Expt. 2. Influence of flower thinning on fruitfulness. This experiment was planned to determine if the number and position of flowers on the inflorescence were critical for fruit set. Two identical experiments were established for 'Manzanillo' and 'Picual'.

The thinning treatments consisted of eliminating one-half, three-fourths, and seven-eights of the flowers in each inflorescence at 3 positions (basal, apical, and longitudinal) and an unthinned control. The 10 treatments were applied at random to different branches per tree. For each branch, all flowering shoots received the same treatment, and 8 of such shoots were tagged for observation. Four replications (trees) of each cultivar were used.

Observations were determined as in Expt. 1, except that perfect flower and fruit counts were done at 8, 12, 22, and 39 days after FB, and shoot measurements were made at 13 and 48 days after FB. In addition, the weight of 20 fruit per treatment was determined at harvest.

For both experiments, the influence of different fruitfulness indices on crop efficiency was evaluated by correlation analysis. The parameters used are included in Table 2. In addition, analysis of variance and the Duncan's multiple range test were used for mean separation.

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