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Measuring fig quality using near-infrared spectroscopy

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Abstract

Sorting of dried figs prior to inspection is labor-intensive and somewhat complex. We examined the potential of using near-infrared spectroscopy (NIRS) to automate sorting of dried figs. Calimyrna and Adriatic types were inspected by hand using established criteria. For both varieties, approximately 100 passable figs and 100 figs each for the infested, rotten, sour, and dirty defect categories were examined using NIRS and partial least-squares regression (PLS). Correct classifications for these varieties ranged from 83 to 100%. About twenty PLS factors were used to make the predictions. These results indicate that the use of NIRS to help automate inspection for dried fig processing is feasible. However, the large number of wavelengths needed for prediction, as indicated by PLS beta coefficients, indicates that implementing NIRS in fig sorting may require an instrument capable of reading numerous wavelengths rather than a more economical filter-based instrument. Published by Elsevier Science Ltd.

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1. Introduction

In the decade between 1988 and 1997, an average of 14,840 metric tons of dried figs per year were produced in California, with an average value of US$16.4 million (CDFA, 1998).

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Commercial dried fig production in California is primarily from four types: Calimyrna, Adriatic, Kadota, and Mission (Simmons, 1931). The Adriatic type is represented by several cultivated varieties, including Conadria, DiRedo, Earlimont, and Tena (CFAB, 1998). Calimyrnas, unlike the other three varieties, require pollination by the fig wasp *Blastophaga psenes* (L.) in order to produce mature fruit (Michailides et al., 1996). The ostiole (the opening at the apical end of the fruit) is larger on Calimyrnas than the other three varieties, making the Calimyrnas somewhat more susceptible to insect pests, pathogens, and contamination with soil.

All dried figs produced in California must undergo a complex manual inspection by the Dried Fruit Association (DFA) of California (Howard, 1929; Condit, 1947). Groups of 100 dried figs are randomly selected. Each fig is cut open, flattened out, examined on both sides, and graded as either defective in one of five categories — insect infested, moldy, sour, filthy, or worthless — or else as passable. A fig is considered "insect infested" if there are carcasses, frass, webbing or feeding damage indicating the presence of nitidulid beetles or larvae of the navel orangeworm *Amyelois transitella* (Walker), the Indian meal moth *Plodia interpunctella* (Hübner), or the vinegar fly *Drosophila melanogaster* Meigen. However, figs with fig wasps or two or fewer ants are not considered insect-infested. The "moldy" condition is caused by fungi of the genera *Aspergillus* and *Fusarium*, and the "sour" condition is caused by a variety of yeasts and bacteria (Michailides et al., 1996). Figs not passing this inspection can not be sold for human consumption, so fig producers hire sorters and inspectors to perform similar examination prior to official inspection and prior to selling figs to processors. Automation of the sorting procedure could benefit the dried fig industry by saving labor costs, making fig producers less vulnerable to year-to-year variability in the labor supply, and by increasing the overall quality of figs shipped to packers. It is also hoped that sorting technologies could reduce postharvest fumigant use, either by using sorting instead of fumigation to disinfest product coming in from the orchard or by using certification to meet phytosanitary requirements for export.

Near-infrared spectroscopy (NIRS) has been used in a variety of agricultural and food technology applications (Panford, 1987). Recent applications include the classification of insect species (Dowell et al., 1999), detection of internal insect pests of wheat (Ridgway and Chambers, 1996; Dowell et al., 1998), and distinguishing between unparasitized weevil larvae in wheat and those parasitized by wasps (Baker et al., 1999). In this technique, the amount of light absorbed by materials is influenced by the number of molecules of specific constituents. Thus, quantitative information indicating the amount of chemical components such as water, oil, starch, sugar, or protein in agricultural products is measurable with NIRS (Murray and Williams, 1987). Fundamental absorptions usually occur in the mid-IR region (2500–15,000 nm), but 1st, 2nd, and 3rd absorption overtones occur in the NIR region (700–2500 nm). Advantages of measuring absorption in the NIR instead of mid-IR include lower sensor costs and less sample preparation. Statistical techniques such as partial least squares regressions (PLS), Fourier transforms, or neural networks are used to correlate NIR spectra with components of interest. Passable and defective figs should differ in their composition of water, sugar, protein, etc. Thus, NIRS should be sensitive to these differences and provide an objective means of classifying figs.

The objective of the present study was to examine the feasibility of using NIRS spectroscopy to distinguish between passable and defective figs, and between the various defect categories.

2. Materials and methods

2.1. Fig samples

Samples of Adriatic and Calimyrna figs from the 1998 crop year were obtained from DFA of California following inspections according to established procedures. Dried figs brought to packers for processing were randomly sampled by diverters, and these samples were presented to DFA of California for inspection. DFA inspectors took 100 figs from each of these samples. Each of these figs was cut in such a way that the ostiole remained intact and spread out so that, instead of being hollow and bulbous, the fruit formed a single flat sheet. Following cutting, each fig was inspected according to official criteria (Howard, 1929):

1. Insect Infested — Dried figs are regarded as insect infested if:
   - 1.1. worms or insects or their pupae, dead or alive, are present in the interior of the dried figs; or
   - 1.2. the excreta are distributed in the interior of the dried figs.

2. Moldy — Dried figs are regarded as moldy if the fig shows a moldy or smutty condition in an area equaling or exceeding 0.5 cm.
3. Sour — Dried figs are regarded as sour if they are:
   - 3.1. fermented as indicated by distinct sour taste or odor, or the darkening in color characteristic of fermentation or souring, or,
   - 3.2. infested with internal rot (endosepsis).

4. Filthy — Dried figs are regarded as filthy if contaminated with dirt or extraneous matter.
5. Worthless — Dried figs are regard as worthless if so immature, woody, or fibrous as to be practically valueless as a food.
6. “Passable Figs” — means those individual specimens of dried figs or separate pieces of sliced figs which are not regarded as defective figs.

Figs classified as “worthless” rarely get to DFA inspectors, so this category was not included in the current analysis. For the Adriatic type, inspectors collected about 100 passable and 370 defective figs. For the Calimyrna type, inspectors collected about 100 passable and 270 defective figs. DFA inspectors stored figs at 4°C in separate plastic bags for up to several weeks until a sufficiently large quantity was gathered. These figs were then shipped to the USDA ARS Grain Marketing and Production Research Center, Manhattan, KS, for NIR analyses. Dried figs are produced on approximately 6500 hectares (CFAB, 1998), all in California and primarily in three counties, and all dried figs produced in California are inspected by DFA of California. Thus, samples obtained by these procedures are representative of commercially-produced figs in the US in 1998.

2.2. NIR spectra collection

Although the figs had been cut open during inspection, each fig was closed during scanning to mimic scanning uncut figs. A diode-array NIR spectrometer (Perten Instruments, Springfield, IL) was used to collect 15 spectra (400–1700 nm) from a 16 mm diameter area on each side of single figs placed manually on a reflectance fiber probe. The area selected for scanning did not include the cut. The 15 spectra for each side were averaged and stored, resulting in two average spectra per fig. The illumination fiber was 2 mm diameter and the reflectance fiber was 7 mm diameter. A sleeve on the outer portion of the reflectance probe held the fig 18 mm from the fiber ends. Data collection required about 1 s per side. Spectralon with 20% reflectance (Labsphere Inc., North Sutton, NH) was used as a baseline. The 400–1700 nm region recorded by the spectrometer is the limit of the Perten NIR sensor.

2.3. Data analysis

Spectra were analyzed using partial least squares (PLS) regression (Martens and Naes, 1989) and GRAMS software (Galactic, Salem, NH). The signal below 550 nm had excessive noise due to low energy and low sensor sensitivity in this region, thus only the 550–1700 nm region was used. Passable figs were assigned a value of 1.0 and defective figs assigned a value of 2.0. When analyzing data, a cutoff was selected that resulted in the greatest number of correctly classified figs. For developing a calibration set, cross-validation was used to select calibration samples. Cross-validation attempts to emulate predicting unknown samples by using the training data set itself. To do this, one sample was removed from the data set, a calibration developed with the remaining samples, then the removed sample predicted. This was repeated for all samples. A calibration was selected that resulted in the lowest residual sum of squares when using the least number of factors. PLS factors are somewhat analogous to regression coefficients and represent common variations in spectral data combined with changes in spectra that correspond to the regression constituents. Including more factors in calibrations can improve predictions, but including too many can over-fit the data. A maximum of about 50% of the total number of figs and only figs which had both sides predicted correctly as passable or defective in the cross-validation were used in the final calibration. All remaining figs were used in the prediction set. For all prediction analyses, the entire fig was considered defective if either side was predicted as defective.

PLS reports the importance of wavelengths used in calibrations as beta coefficients. For any given wavelength, the absolute value of the beta coefficient indicates how important that wavelength was for classifications. Thus, beta coefficient plots can be compared to NIR absorptions of specific functional groups to indicate what chemicals contribute to unique NIR absorptions between samples.

3. Results and discussion

NIRS distinguished between passable and defective figs with $\geqslant$88% agreement with manual inspection for Adriatic and Calimyrna figs (Tables 1 and 2). When examining the classification rates for specific defect categories, all defects were predicted with similar accuracies, with classification accuracies ranging from about 83% to 100% agreement with manual inspection. Both types were classified with similar accuracies. Twenty factors were used in the Adriatic calibration and 23 factors were used in the Calimyrna calibration.

Table 1
Classification of Adriatic figs using NIR spectra and partial least squares regression (20 factors)[a]

Class	Correctly Classed[b] (%)	n[c]	Average[d]	Standard deviation
Calibration set[e]				
Passable — all	100.0	100	1.22a	0.18
Defective — all	92.0	274	1.92b	0.24
Defective — dirty	100.0	22	2.01b	0.22
Defective — infested	91.5	94	1.91b	0.26
Defective — moldy	88.6	88	1.89b	0.25
Defective — rotten	94.3	70	1.93b	0.23
Prediction set				
Passable — all	92.0	100	1.39a	0.25
Defective — all	89.0	280	1.92b	0.26
Defective — dirty	90.9	22	2.08b	0.26
Defective — infested	95.8	96	1.95b	0.24
Defective — moldy	87.0	92	1.87b	0.27
Defective — rotten	82.9	70	1.89b	0.25

[a] Means in a column for the same set and followed by the same letter are not significantly different at the $P = 0.05$ level.

[b] Refers to agreement with classification determined by manual inspection.

[c] n = number of spectra which equals 2 × the number of figs.

[d] Average = Average predicted value where 1 = Passable, 2 = Defective, and cutoff value of 1.75 was used.

[e] Prediction results of the calibration set were achieved through cross-validation.

Table 2
Classification of Calimyrna figs using NIR spectra and partial least squares regression (23 factors)[a]

Class	Correctly classed[b] (%)	n[c]	Average[d]	Standard deviation
Calibration set[e]				
Passable — all	100.0	100	1.18a	0.17
Defective — all	92.5	372	1.95b	0.20
Defective — dirty	92.3	52	1.97b	0.16
Defective — infested	95.0	120	1.99b	0.16
Defective — moldy	88.0	100	1.92b	0.23
Defective — rotten	94.0	100	1.92b	0.19
Prediction set				
Passable — all	88.0	100	1.44a	0.28
Defective — all	93.7	380	1.96b	0.22
Defective — dirty	100	54	2.03b	0.20
Defective — infested	98.4	126	1.96b	0.19
Defective — moldy	94.0	100	1.98b	0.25
Defective — rotten	84.0	100	1.93b	0.23

[a] Means in a column for the same set and followed by the same letter are not significantly different at the $P = 0.05$ level.

[b] Refers to agreement with classification determined by manual inspection.

[c] n = number of spectra which equals 2 × the number of figs.

[d] Average = Average predicted value where 1 = Passable, 2 = Defective, and cutoff value of 1.8 was used.

[e] Prediction results of the calibration set were achieved through cross-validation.

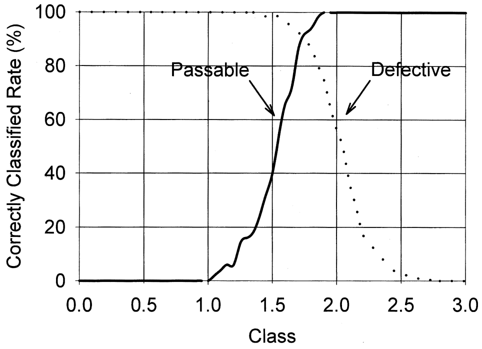

Fig. 1. Distribution of class values for Adriatic figs using NIR spectroscopy. High class numbers correspond to defective figs.

When examining the predicted values, where 1 = passable and 2 = defective, the defective figs had an average predicted value significantly ($P = 0.05$) higher than passable figs. No significant difference was seen in predicted values of specific defect categories (dirty, infested, moldy, or rotten). The r^2 values for these calibrations were 0.71 for Adriatic figs and 0.73 for Calimyrnas.

The correct classifications achieved for all defective and passable figs in the prediction sets ranged from 88% to 93.7%, which was slightly lower than the range of 92–100% achieved with the calibration set (Tables 1 and 2). This good agreement indicates that the calibration does not over- or under-fit the data.

The classification rates shown in Tables 1 and 2 were derived by selecting a class cut-off value that resulted in the maximum number of correctly classified passable or defective figs. This value was 1.75 for Adriatic figs and 1.8 for Calimyrna figs. Fig. 1 shows how the classification rate changes if a different cut-off value is selected for the prediction set. For example, increasing the cut-off value from 1.75 to 2.00 increases the classification of passable

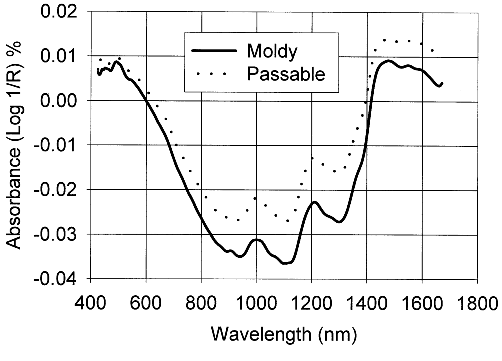

Fig. 2. NIR absorption spectrum for individual Adriatic figs; one "passable" and one classified in the "moldy" defect category.

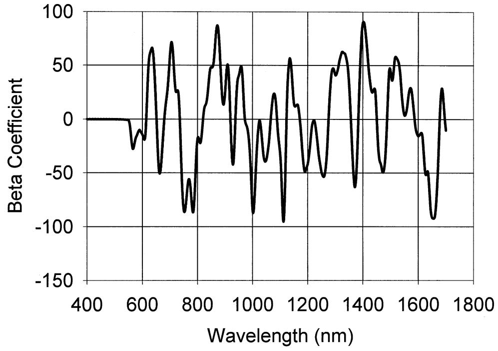

Fig. 3. Beta coefficients used in the calibration equation for classifying Adriatic figs.

figs from about 90 to 100% while correspondingly lowering the classification rate of defective figs from about 90 to 60%. Similar graphs can be generated for Calimyrna figs.

Fig. 2 shows a typical NIR spectrum for figs. The absorbance peaks around 1000, 1200, and 1400 nm are typical for agricultural materials (Williams and Norris, 1987). Fig. 3 shows a plot of the beta coefficients which show the wavelengths used in Adriatic fig classifications. The beta coefficients for Calimyrna figs were similar. It appears that PLS selects wavelengths throughout the NIR region, indicating that overtones due to absorptions of CH, OH, and NH functional groups all contribute to classifications. Thus, it is unlikely that any one constituent, such as moisture or sugar content, is solely responsible for classifications. This is not surprising, given the complex nature of these classifications. The beta coefficient peaks throughout the NIR region also indicate that it may be difficult to select only a few wavelengths that could be used for classifications.

These data show that it is practical to separate passable figs from those of different defect classes using reflectance NIRS. Using NIRS in reflectance mode offers high throughput and, in principle, NIRS could be used as the basis of automated sorting. These data indicate that such classification will likely require a more sophisticated instrument capable of continuous scans rather than a more economical filter-based instrument. While these results were obtained from hand-placed figs, similar results should be achievable with an automated system that is capable of scanning figs from two sides. Future research will include examining the biochemical basis of wavelengths contributing to the PLS distinction between passable and defective figs. Given grower concerns about labor cost and availability, further efforts are merited for development and transfer of NIRS technology for sorting figs.

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