# OPTICAL DETECTION OF MEALINESS IN APPLES USING LASER TDRS

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Abstract

Mealiness is a textural attribute related to an internal fruit disorder that involves quality loss. It is characterised by the combination of abnormal softness of the fruit and absence of free juiciness in the mouth when eaten by the consumer. Recent research concluded with the development of precise instrumental procedure to measure a scale of mealiness based on the combination of several rheological properties and empirical magnitudes. In this line, time-domain laser reflectance spectroscopy (TDRS) is a new medical technology, used to characterise the optical properties of tissues, and to locate affected areas like tumours. Among its advantages compared to more traditional spectroscopic techniques, there is the feasibility to asses simultaneously and independently two optical parameters: the absorption of the light inside the irradiated body, and the scattering of the photons across the tissues, at each wavelength, generating two coefficients ($\mu a$, absorption coeff.; and $\mu 's$, transport scattering coeff.). If it is assumed that they are related respectively to chemical components and to physical properties of the sample, TDRS can be applied to the quantification of chemicals and the measurement of the rheological properties (i.e. mealiness estimation) at the same time. Using VIS & NIR lasers as light sources, TDRS was applied in this work to Golden Delicious and Cox apples (n=90), conforming several batches of untreated samples and storage-treated (20°C & 95%RH) to promote the development of mealiness. The collected database was clustered into different groups according to their instrumental test values (Barreiro et al, 1998). The optical coefficients were used as explanatory variables when building discriminant analysis functions for mealiness, achieving a classification score above 80% of correctly identified mealy versus fresh apples.

## 1. Introduction

Nowadays, consumers' decision at purchase is affected by both external aspect and internal quality of fruits. Among the quality parameters that a consumer can find in apples, mealiness is a main issue. It has been defined as a negative attribute of sensory texture that combines the sensation of a dis-agregated tissue with the sensation of lack of juiciness. Mealiness is associated with late harvest, long term storage. Mealiness asset may be also accelerated by temperature treatments combined with extremely high relative humidity (De Smedt, 2000).

The characterisation of mealiness has been done traditionally by means of sensory panels defining sensorial. A recent EC Project (FAIR CT95-0302) was devoted to the comparison between sensory and instrumental measurements for mealiness assessment, mainly in apples (Barreiro et al, 1998) (De Smedt et al, 1998) but also in peaches and tomatoes. Using a mechanical test (confined compression of probes), already widely used in the evaluation of food properties, redefinition of mealiness in apples and peaches in terms of rheological properties was proposed following human priorities in mealiness perception. The instrumental mealiness scale, gathering loss of crispness, hardness and juiciness. correlates well with sensory mealiness.

Also different approaches for future non-destructive methods were attempted during the EC Project. Different techniques were applied during collaborative testing: NIR spectroscopy, low mass impact, acoustic impulse response and ultrasonic wave propagation through fruit tissues, and NMR. None of them on their own showed good prospective in relation to mealiness assesment. NIR spectroscopy (focused on water distribution detection) and low mass impact response (to characterise hardness) showed to be adequate for the segregation of several mealiness stages in peaches (Ortiz, 2000).

Nevertheless, the development of standing-alone non destructive techniques is still interesting, specially if they are fast and could be engineered into an automatic classification system. TDRS or TRS (time-domain resolved spectroscopy or time reflectance spectroscopy) is a non conventional spectroscopic technique that has been developed for use in the field of medicine, for the detection of discontinuities in tissues and the location of human tumours (Cubeddu et al XXX). In this work the objective was to apply time-domain resolved reflectance spectroscopy for the characterisation of the optical properties of selected fruits, which can be used for the non-destructive internal evaluation of several aspects of fruit quality, as it is the case of mealiness.

## 2. Materials and methods

The objective for this work was the study of applicability of the TDRS technique to the detection of mealiness in apples. Therefore, different samples were prepared along the previous months:

1. Apples with "natural mealiness", in order to study if it is present in apples harvested late in the campaign: the UPM staff moved to the orchards (Almunia de Dª Godina, Zaragoza) the last week of October (late harvest), to pick up selected Golden Delicious apples to conform two groups, the *a priori* non mealy apples and the mealy ones. From the whole harvest, 25 "fresh" and 25 "possibly mealy" were packed and sent to Milan in November. The "a priori mealy" samples were selected on the trees from the whole harvest using two subjective criteria: external colour (mealy batch more golden than the fresher one) and tactile hardness.
2. Apples with mealiness induced in chamber storage: colleagues at the Catholic University of Leuven (Belgium) prepared along the autumn some samples from the Cox variety, harvested early in the season and stored until November in specific conditions: 20 of them were kept inside an ULO chamber (ultra low oxygen) to

preserve their freshness at maximum levels; other 20 apples were kept along 16 days into an atmosphere of 95% relative humidity and 20°C, to promote the development of mealiness. Not all of them were expected to be finally mealy, as indicated by previous studies.

The use of the expression "a priori mealy" refers to the fact that, up to date, there is not a non destructive method to know if each unit of a batch of apples is really mealy until you destroy them. The only destructive test that has been proven to be reliable characterising the mealy samples combines information from mechanical behaviour and juice released to classify the samples according to their level of instrumental mealiness.

## 2.1. Reference tests (firmness, colour and chemicals) and TDRS measurements

The tests carried out on the samples can be summarised as indicated below. Test are listed in chronological order.

TDRS measurements. TDRS is based on the measurement of the broadening of a short light pulse, transmitted across a turbid medium (fruit tissues). The light source is a laser beam, monochromatic then, but tuneable at several wavelengths. The light is injected in the fruit through the intact skin by means of fibre optics positioned perpendicularly to the equator of the fruit. The light flux crosses the tissues and part of it finds its way out of the sample at a particular region adjacent to the injection point. This portion of reflected light was recovered with other fibre optics placed at about 20 mm in parallel to the injection ones. The three-dimensional light region formed by the light which is capable of entering the recovering fibres is commonly named "banana" after the shape that is constructed by the optical paths of the photons with larger probability of being recovered after suffering internal reflection. If an adequate theoretical model is used for the experimental analysis of data and several hypothesis are established, it is possible to calculate at the same time the absorption coefficient and the transport scattering coefficient at each wavelength, with good precision. The TDRS equipment used in these work is described in detail in the following references: (Cubeddu *et al.* 1994a; Cubeddu *et al.* 1994b; Cubeddu *et al.* 1999)

For this study, the absorption and transport scattering coefficients of both sides of each sample were registered at several wavelengths: far-visible (672, 750 & 818nm using diode lasers as light sources) and NIR (form 900 to 1000nm, at steps of 10nm using a tuneable laser).

Confined compression test. Using a Texture Analyser TA-XT2 a maximum deformation of 2.5mm was applied at 20mm/min speed rate on cylindrical probes of 1.7 cm height and diameter. Deformation was immediately removed at the same speed rate; two repetitions were made per fruit (one per side) using the average for the subsequent analyses for this load/unload test. Cylinders were confined in a disk which had a hole of the probe size (see Figure 1). The rod employed for the compression test was 15.3 mm diameter to avoid any contact with the disk during testing. A filter paper (Albet n° 1305 of 77.84 $gr/m^2$) about the size of the disk was placed beneath the disk in order to recover the juice extracted during the compression test. The following parameters (the name within brackets refers to later abbreviations of the variables) are registered through this test:

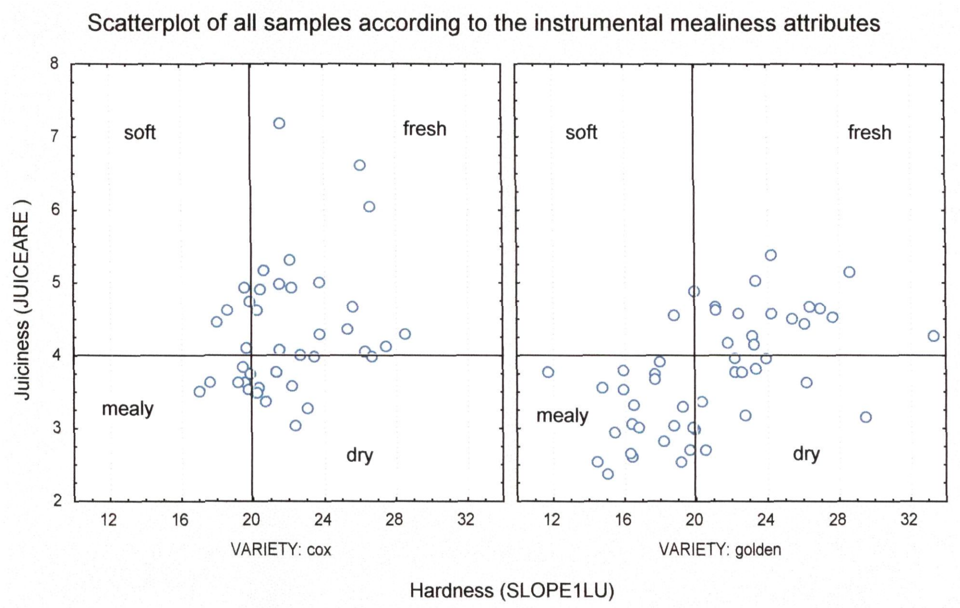
- Maximum force (F1LU, N), first peak with 0.5N threshold
- Deformation for F1 (D1, mm)
- Hardness (SLOPE1LU, N/mm) force-deformation slope for F1LU and D1
- Force for max deformation, 2.5mm (F2LU, N)
- Degree of plasticity, calculated as the percentage of plastic deformation over the total deformation
- Juice area (JUICEARE, $mm^2$) recovered in the filter paper placed underneath the probe during the test.

Table 1. Samples measured, harvest/storage treatment, expected (*a priori*) textural state and wavelengths measured with TDRS equipment.

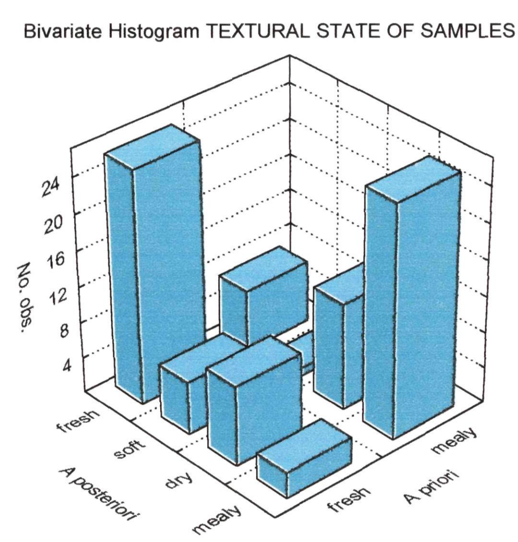
| Apple | # fr | Origin | Treatment | Expected state | TDRS Far VIS λs (nm) | TDRS NIR λs (nm) |
|---|---|---|---|---|---|---|
| Cox | 20 | Belgium | ULO storage, 16 days | "fresh" | 672, 750, & 818 | 900-1000 (each 10nm) |
| Cox | 20 | Belgium | RH 95%, 20°C, 16 days | "mealy" | 672, 750, & 818 | 900-1000 (each 10nm) |
| Golden Delicious | 25 | Spain | Late harvest | "fresh" | 672, 750, & 818 | 900-1000 (each 10nm) |
| Golden Delicious | 25 | Spain | Late harvest (overripe) | "mealy" | 672, 750, & 818 | 900-1000 (each 10nm) |

## 3. Results

Using the variables extracted from confined compression, the samples were labeled out of four textural stages (“mealy”, “dry” but firm, “soft” but juicy, “fresh”), three stages (“mealy”, “nonmealy” = dry or soft, “fresh”) and two stages (“mealy”, “fresh”). A sample was labelled as “soft” when SLOPE1LU<20 N/mm; it was “dry” if JUICEARE<4$cm^2$; a “mealy” sample has to be soft and dry. New variables were added to the analysis (MEALY4, MEALY3 and MEALY) with the codes of this posterior classifications of samples into mealy stages.




A first comparison can be done between a priori and destructive classification, as shown in figures 1 & 2.




Discriminant analysis functions were built using the TDRS coefficients (variables MA672 to MA1000, and MS672 to MS1000) as explanatory variables for the classification of samples into two textural categories (mealy vs, fresh), three (mealy, nonmealy, fresh) or four (mealy, dry, soft, fresh). As the number of individuals for each stage were not homogeneous, a priori classification probabilities were calculated as proportional to group sizes. The classification functions were modelled with a stepwise approach, selecting or removing each variable by the analysis of the unique contribution of the respective variable to the discriminatory power of the model

A first model was created using both varieties together for the discrimination between "mealy" and "fresh" states. 7 TDRS variables were used in the model achieving a percentage of correctly classified individual fruits of 90.0%. More misclassifications were obtained proportionally for mealy samples incorrectly predicted as fresh (8/21), than the reverse case (5/56).

Classification Matrix
Rows: Observed classifications
Columns: Predicted classifications

| | Percent Correct | fresh p=,67778 | mealy p=,32222 |
|---|---|---|---|
| fresh | 91,80 | 56 | 5 |
| mealy | 72,41 | 8 | 21 |
| Total | 85,56 | 64 | 26 |

The variables in the classification functions were both absorption coefficients and scattering coefficients at the chlorophyll absorption peak (670nm) and a wide range of NIR wavelengths.

The segregation ability of this type of model was validated using alternatively half of the samples as the learning subset and the other half as the anonymous subset. A randomisation algorithm was used to generate the subsets conforming a distribution of 33 fresh plus 13 mealy per group. The results are expressed in the following table:

| Iteration | "Fresh" percent correct | "Mealy" percent correct | Total percent correct |
|---|---|---|---|
| 1 | 93,10% | 81,25% | 88,89% |
| 2 | 78,13% | 76,92% | 77,78% |
| 3 | 90,63% | 69,23% | 84,44% |
| 4 | 89,66% | 50,00% | 75,56% |

When trying to estimate more stages of mealiness, the performance of the new models built decreased considerably. The model estimating MEALY3 ("fresh", "nonmealy" and "mealy") scored 72.2% of well classified fruits on both varieties, while the estimation of MEALY4 ("fresh", "dry", "soft" and "mealy") achieved 73.3%. In both cases it was noticed that the central classes ("dry", "soft" or the union of them ="nonmealy") were the worst predicted groups.

In order to reduce the number of variables in the models, new analysis was performed with more restrictive conditions in the number of wavelengths and the tolerance level of the stepwise method. It was seen that all the remaining variables in the models were absorption coefficients, and all the scattering ones were removed in the stepwise algorithm. The wavelengths remained around the 670nm peak an the centre-left of the NIR region studied (960-980nm).

| FIVE VARIABLES<br>Classification Matrix for all samples | | | |
|---|---|---|---|
| Rows: Observed classifications | | | |
| Columns: Predicted classifications | | | |
| | Percent | fresh | mealy |
| | Correct | p=,67778 | p=,32222 |
| fresh | 90,16 | 55 | 6 |
| mealy | 72,41 | 8 | 21 |
| Total | 84,44 | 63 | 27 |

| THREE VARIABLES<br>Classification Matrix for all samples | | | |
|---|---|---|---|
| Rows: Observed classifications | | | |
| Columns: Predicted classifications | | | |
| | Percent | fresh | mealy |
| | Correct | p=,67778 | p=,32222 |
| fresh | 91,80 | 56 | 5 |
| mealy | 65,52 | 10 | 19 |
| Total | 83,33 | 66 | 24 |

## 4. Discussion

As it has been observed in other studies, the obtaining process of mealy samples to carry out research is not always a straight forward routine. The Cox samples stored under strict relative humidity and temperature conditions to promote mealiness development, not always shown at the end of the treatment a mealy stage. In fact, a low percentage of them were found as mealy in this study, a fact that has been supported previously by other authors. This may indicate that there are more factors affecting mealiness that just the humidity and temperature during storage, harvest date and variety. On the other hand, it seems clear that Golden apples late harvested can develop mealiness by themselves and already "in the tree", without a shelf life. This is of high importance for apple growers when, due to climatic conditions or labour problems, they can not pick all the harvest on time, leaving part of it on the orchard.

The predictive models that estimate two instrumental mealiness states using absorption and scattering TDRS coefficients show high discrimination performance when classifying samples from both apple varieties (85%). The stability of this performance in the validation process is good and it only decreases in one case, affected mainly by a misclassification of the "mealy" group (75%) that has to be studied further.

Models estimating more than two states offer much lower segregation abilities. The prediction of four stages shows a score of 72%, and the prediction of three gives a percentage of 73% of well classified fruits. This figures are not suitable for a classification technique. The fact that the highest misclassification scores were found in the central groups (fruits other that really mealy or really fresh) suggests that the used the whole TDRS technique itself is not adequate to detect the individual quality parameters involved in the development of mealiness (apparent drought of tissues, softening) but it is useful when they are combined. It can be also a problem of the system set-up or just a matter of detection resolution.

The trial with less number of variables in the models was satisfactory, reducing the performance only 2% form 7 variables (7 correspondent wavelengths) to the last model with 3 variables and wavelengths. This point will be of great importance when the system will be scaled down to fit industry requirements of low cost, ease of operation and stability.

## 5. Conclusions

Time domain reflectance spectroscopy has been proven to be a useful technique to identify mealiness in apples non destructively. Error rates in classification models discriminating mealy samples from nonmealy ones are low. The segregation between more than two textural stages of mealiness (other than "fresh" and "mealy") can not be achieved so far, and requires more studies. The technique, new in the field of food sensors, shows interesting potentials for internal parameter detection of quality attributes and disorders.

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## References

Pilar (varias)

Coral

Informe final Mealiness