FRUIT QUALITY SENSING: POST-HARVEST RIPENESS

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ABSTRACT

Firmness sensing of selected varieties of apples, pears and avocado fruits has been developed using a nondestructive impact technique. In addition to firmness measurements, postharvest ripeness of apples and pears was monitored by spectrophotometric reflectance measurements, and that of avocadoes by Hunter colour measurements. The data obtained from firmness sensing were analyzed by three analytical procedures: principal component, correlation and regression, and stepwise discriminant analysis. A new software was developed to control the impact test, analyse the data, and sort the fruit into specified classes, based on the criteria obtained from a training procedure. Similar procedures were used to analyse the reflectance and colour data. Both sensing systems were able to classify fruits with good accuracy.

1. INTRODUCTION

Firmness is an important quality factor which closely relates to fruit maturity and ripeness. There is a variability in fruit firmness among individual fruits of the same variety harvested from the same place of origin. Fruit firmness can also be greatly affected by postharvest treatments. Fruits with different firmness do not ripen evenly, creating problems in storing, handling and marketing. Therefore, it is desirable to sort fruits into different firmness groups. The long-term objective of our research is to develop a technique for on-line firmness measurement of individual fruits so that they can be accurately graded by firmness.

There has been an increased interest in firmness measurement of fruits. Other researchers have tried quasi- static force-deformation (Mehlschau *et al.*, 1981) and, more recently, mechanical resonance and acoustic impulse techniques (Chen *et al.* 1992). We have found in our previous studies (García *et al.* 1988 Jarén *et al.* 1992, Correa *et al.*, 1992) that the response of fruit to a small mechanical impact correlates well with firmness. During the past years, we have made several studies on firmness measurement and postharvest monitoring of apples, pears, and avocadoes, leading to the development of a procedure for automatically classifying fruits into different firmness groups. This paper presents our research activities which include:

1. Acquisition of data on impact firmness testing and on optical measurements, of well-controlled fruit samples during postharvest ripening until senescence.
2. Analyses of the collected data, and development of procedures for classifying fruits based on a) the impact response and b) the optical measurements.
3. Verification of the classification procedure on large samples of fruits.

2. MATERIALS AND METHODS

2.1. Impact response of apples, pears and avocadoes.

An impact test was performed using the impact testing system developed by Chen *et al.* (1985). A 50 g instrumented steel rod with a spherical tip of 9.4 mm radius of curvature was dropped from a height of 4 cm onto each pear; 3 cm in the case of apples. The deceleration/acceleration cycle of the rod during impact was measured from the data given by an accelerometer fixed to the indentor.

Blanquilla and Decana pears, Golden Delicious and Starking apples, and Hass avocados were tested continuously for a period of ten days (pears) or three weeks (apples) during post-harvest ripening until senescence. Fruits were allowed to ripen during fixed periods of time at room temperature (18 °C). A total of over 25 parameters of impact response (Jarén *et al.*, 1992, Correa *et al.*, 1992) were analyzed initially by principal component procedures (Judez 1989) for firmness prediction. As a result, eleven parameters were selected for use as initial input variables of a computer programming system for classification based on stepwise discriminant analysis (Discrim) on a group of 10 fruits as a training phase. Impact data from the rest of the fruits (10 again) were then classified as anonimous.

Tests included two (nondestructive) sensing impacts per fruit, two firmness determinations (Magness-Taylor penetrometer with an 8 mm diameter tip) and sensory analysis, along with other parameters, such as mass, radius of curvature (apples and pears), puncture resistance of the skin (avocadoes), soluble solids and pH (apples and pears).

Hass avocadoes were allowed to ripen at room temperature (20° C) and in cold storage (6° C) during 11 and 60 days respectively. Impact tests were applied to ten fruits on the days 5, 7, 9 and 11 and on the days 11, 18, 25, 32, 39, 46, 53 and 60 respectively. They were tested by impact (4 cm drop height), on three equidistant points on the equator of each fruit. Other tests applied to the same fruits were Magness- Taylor penetration, skin puncture (0.5 mm diameter rod) and oil and moisture content.

2.2. Color Development

On each testing date, spectrophotometric measurements were made on samples of 5 fruits (pears and apples) using a Perkin-Elmer 555 spectrophotometer with an integrating sphere. Diffuse reflectance of intact fruits was measured at 10 nm increments within the wavelength range of 340 to 800 nm. The (43) obtained values of R (reflectance) and R' (first derivarive of R) were first analyzed by correlation to determine the wavelenghts in which R and R' values were most correlated to ripeness grade (measured as date of testing). Eleven variables (wavelengths) were thus selected and introduced into the classification software (the same used for impact response data).

In the case of avocados, Hunter parameters L, a, b, C were determined for the skin and for the flesh of samples of fruits at each testing date. These values were analyzed for correlation to firmness parameters.

2.3. Firmness classification of batches of fruit

Seven batches of apples (Golden Delicious and Granny Smith) and pears (Conference and Decana-Comice), divided into two or three ripeness groups = lots were tested through the impact sensing system instrumented with the classification software. Differences between lots were artificially created by subjecting them to different durations of cold storage and ripening periods during different number of days. Table 1 shows the numbers of days in cold storage and subsequent ambient temperature ripening of each group in each fruit batch. Fruits were therefore different between batches, and also the (2 or 3) lots per batch were differently separated in firmness. No avocadoes have been yet subjected to this testing procedure.

Using ten representative fruits in each group, first (training) phase of the system was performed. All fruits were afterwards classified trough the device (working phase), the system using automatically the classification criterium developed previously in the training phase.

TABLE 1

Cold storage (4 ºC) and ripening (18 ºC) treatments applied to the lots of fruits of every sample batch of apples and pears for impact firmness classification by the impact grading system.

Variety	Nº of Fruits	Nº of days: in cold chamber (4ºC) at room temperature (18ºC)		
		LOT 1	LOT 2	LOT 3
Decana pear	90	5/0	0/5	-
Conference pear	128	11/0	0/11	-
Golden apple	77	19/0	14/5	0/19
Granny-Smith apple	133	36/0	15/21	0/36
Golden apple	121	17/0	0/17	-
Grany-Smith apple	119	50/0	15/35	0/50
Granny-Smith apple	94	51/0	23/28	0/51

3. RESULTS AND DISCUSSION

3.1. Initial results. Firmness sensing by impact response.

An impact response classification system was developed (Jarén *et al.* 1992). Results of the application of the system to impact data of different fruit species along with quality indexes calculation, and with the resulting classification criteria have been worked out for selected varieties of apples, pears and avocados. Impact response variables effective for firmness grading along with optical variables effective for ripeness grading are summarized in Table 2. For example, correct grading of 97 to 100 percent of the fruits was obtained when grading by impact response into 3 classes (apples: separated 10 days of ripening, pears: 3 days) and 76 percent when 5 classes (Blanquilla pears: 2 days).

A highly accurate estimation of the firmness evolution of avocados "Hass" was obtained by adjusting a double exponential model (Correa *et al.*, 1992) of an impact response parameter to days of ripening and to Magness-Taylor firmness values. This result shows the accuracy of impact response parameters in estimating avocado firmness. Just one or two impact response variables: TD or MF in the referenced data (see Table 2) were effective in modelling fruit firmness and in classifying avocados into five firmness classes with a 100% accuracy.

TABLE 2

Results of the application of the classification procedure: Variables effective for ripeness/firmness grading by impact and by optical reflectance); pears, apples, avocados (Jarén *et al.*, 1992; Correa *et al.*, 1992).

Impact variables effective for firmness grading	Variables effective for color	
Name, symbol	Reflectance (pears, apples) R and R' at nm:	Hunter Lab parameters (avocados)
1. Total duration, TD	340, 400, 450, 460	a (range from unripe
2. Duration to max. force, FD	500, 510, 530, 550	to overripe: - 7 to 1)
3. Duration to v = 0, TM	560, 570, 600, 620	
4. Increment TD-TM	630, 660, 670, 680	b (10 to 4.5)
5. Max. slope Force/Def., F/T	690, 710, 720, 730	
6. Max. slope Force/Time, F/T	760	$c = \sqrt{a^2 - b^2}$
7. Maximum Force, MF	Decana pears:	(12 to 4)
8. Maximum deformation, MD	670, 630	
9. (F/T) / FD	Golden apples:	
10. Elasticity Modulus EM, or Md^3/2	340, 760, 570	
11. Max. shear stress, SS, or MF/ (MD^3/2)	Starking apples: 340, 530	

3.2. Color Development

Correct grading of 100% of the tested fruits (apples and pears) into ripeness classes was achieved using spectrophotometric reflectance (García *et al.*, 1992). Table 2 shows a list of the discriminating wavelengths used. The eleven selected and the two-three (seven for Blanquilla pears) afterwards used by the system in the classification function are different for the different varieties of fruits. In some cases, only one or two values of R or R' were sufficient for 100% correct classification in three lots (first, intermediate and last of testing dates, see above). When attempting to classify into all lots = testing dates (5, 7 or 8 lots, depending on variety) percentages of correctly classified varied between 62 to 78 for R values, 50 to 82 for R' values. Best results were obtained for Decana pear and for Starking apples.

These results showed the feasibility of using spectral reflectance data for fruits quality grading using the same classification software developed for impact response parameters.

As for avocado color, evolution of color parameters was closely correlated to firmness evolution during most of the postharvest ripening period (Correa, 1992). Chroma (C) shows a good correlatiom to firmness until pre-senescence.

3.3. Firmness Classification of large batches of fruits

Table 3 shows the variables selected by the automatic procedure in the classification criterium in each test, varying between one (two cases, both pear varieties) and nine (one case, first test of Golden). Table 4 shows the classification results for every batch tested. Percentage of total correctly classified fruits varies between 34 % and 98 %, with very variable percentages for the different lots and varieties.

TABLE 3

Selected impact variables in the classification criteria, for each sample batch.

Variety	Nº of selected variables	Variables (Table 2) (in the order selected)
Decana pear	1	1
Conference pear	1	7
Golden apple	9	11, 7, 2, 5, 9, 6, 10, 8, 3
Granny-Smith apple	3	6, 8, 10
Golden apple	2	9,3
Grany-Smith apple	5	8, 5, 4, 10, 6
Granny-Smith apple	3	4, 11, 1

TABLE 4

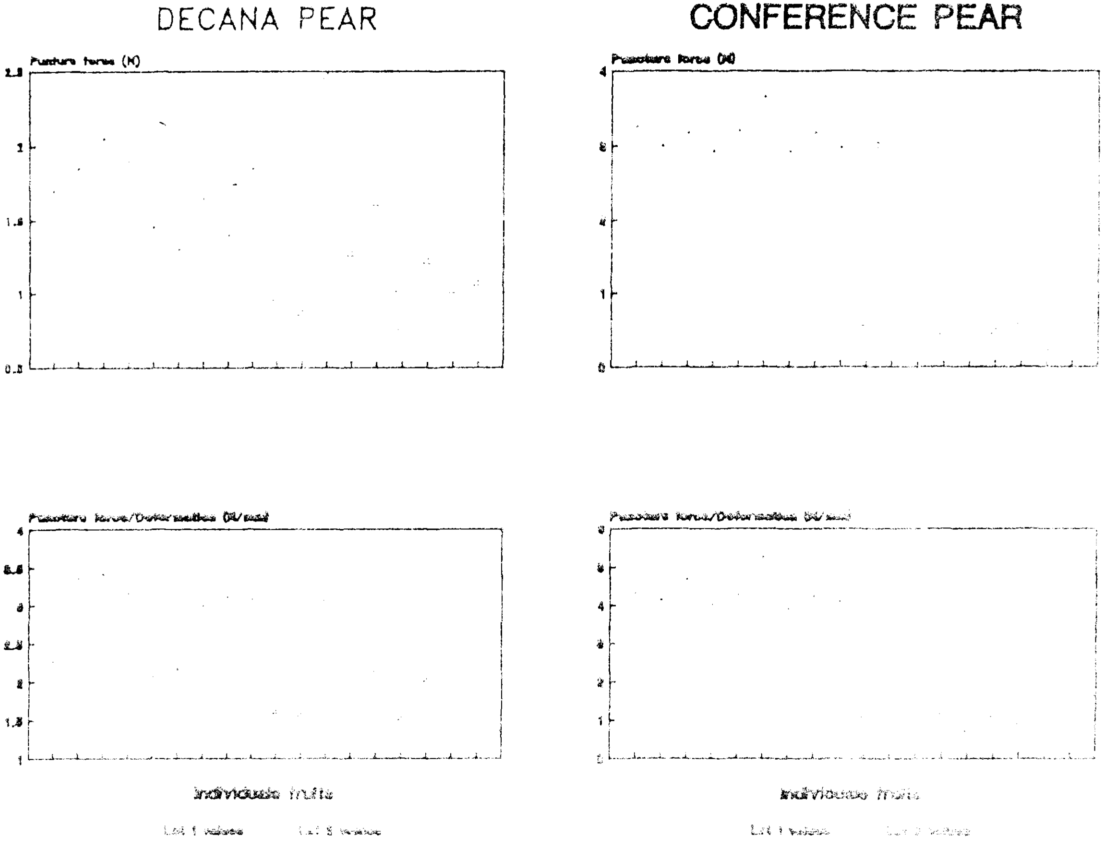
Total and partial percentages of well classified fruits (apples and pears) for every sample batch.

Variety	Correctly classified fruits, %			
	Total	Lot 1	Lot 2	Lot 3
Decana pear	85.5	90.5	81.2	-
Conference pear	97.7	100	94.8	-
Golden apple	70.1	50	68.4	85.3
Granny-Smith apple	33.8	59.5	0	34.3
Golden apple	60.4	62.7	58.1	-
Grany-Smith apple	43.7	47.5	70	12.8
Granny-Smith apple	62.8	90.6	41.9	54.8

No clear relationship is found between percentage of correct classification and either the number of variables selected for the classification criterium, or their order of selection. This leads to the conclusion that any variable may be the most appropriate in any classification process, or also any combination of them, in any order or number may make up the best selection criterium. These variables studied so far, and with the fruit species tested are the appropriate ones to make the procedure feasible for a wide application range.

It is observed that pear varieties both show very good classification results, showing that one variable is sufficient to classify them with high accuracy in the two classes. These results are in accordance with previous results and with the obvious fact that pears suffer a large decrease in firmness during post-harvest ripening (Jarén *et al.*, 1992, Barreiro *et al.*, 1993); therefore, lots are at a higher distance in every impact response parameters. Similar results are likely to be obtained for peaches and other "soft flesh" fruits (Ruiz-Altisent, 1991).

Observing the sample batches which were badly classified, one question arises: Is it a fault of the procedure or the system, or is it a mistake of the training process, i.e. of the selection of the lots. In this latter case: Which are the values of other objective firmness parameters of these same fruits, to be compared with the results obtained by the classification based on impact sensing?. Only the firmness parameters of the ten fruits used for the training phase are available. Figures 1a, 1b shows values of puncture resistance (N) and force/deformation at puncture (N/mm) for both varieties of pears and apples. For Conference, it is very apparent that both groups of pears belonged to largely separated firmness levels: The results of the impact classification show that the 128 fruits were correctly classified in a 98% in both lots and using one only variable (Tables 3 and 4). The 90 fruits of Decana pears were well classified in a 85.5 %; their puncture force/deformation (Figure 1) shows that (at least) two fruits were apparently mixed: it can be guessed that the impact device classified them accordingly into the "incorrect" lots, including the fact that some bias may have been introduced to the classification criterium. The same data for apple varieties show the relative distances and variation in firmness for the different cases studied, to be compared with the results shown in Tables 3 and 4.


DECANA PEAR

CONFERENCE PEAR

Fig. 1a. Puncture resistance: Force at puncture (N) and Force/deformation (N/mm) of the 10 fruits in each lot (training phase) of Decana and Conference pears. Significant differences in the relative scatter and distance between lots may be observed.

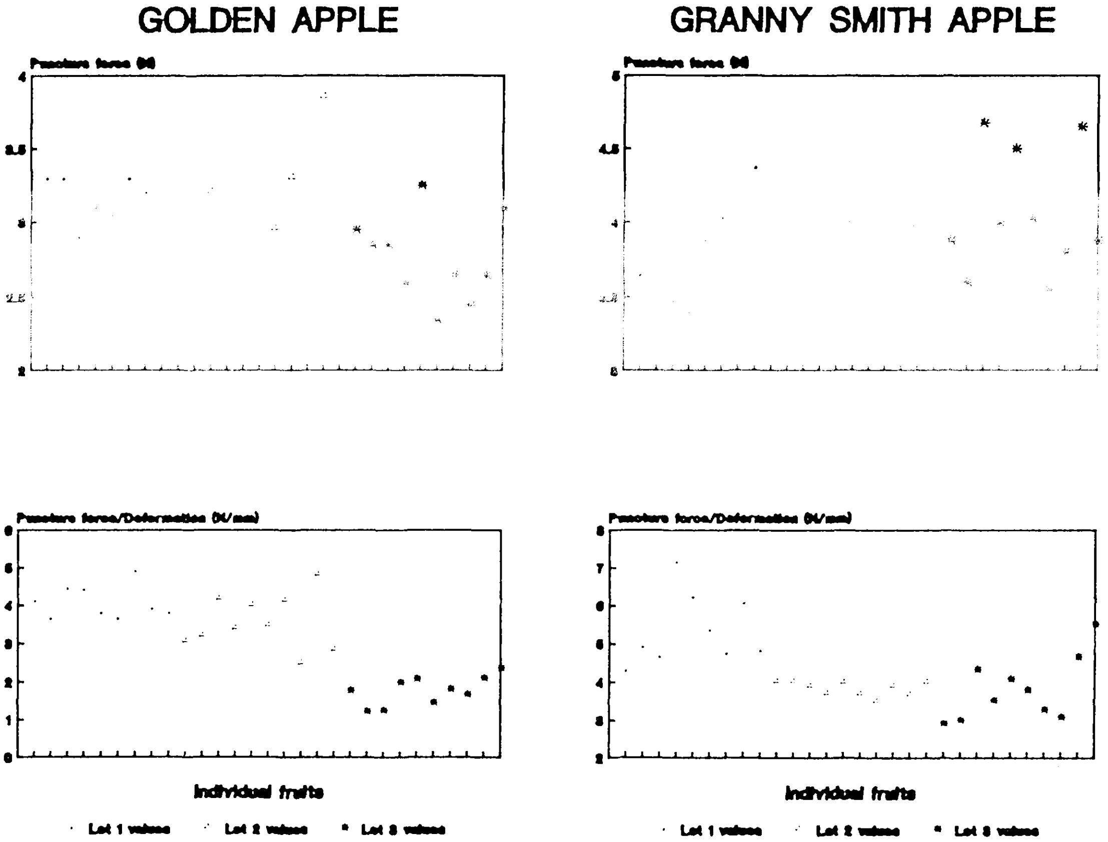


Fig. 1b. Puncture resistance: Force at puncture (N) and Force/deformation (N/mm) of the 10 fruits in each lot (training phase)of Golden and Granny- Smith apples. Significant differences in the relative scatter and distance between lots may be observed.

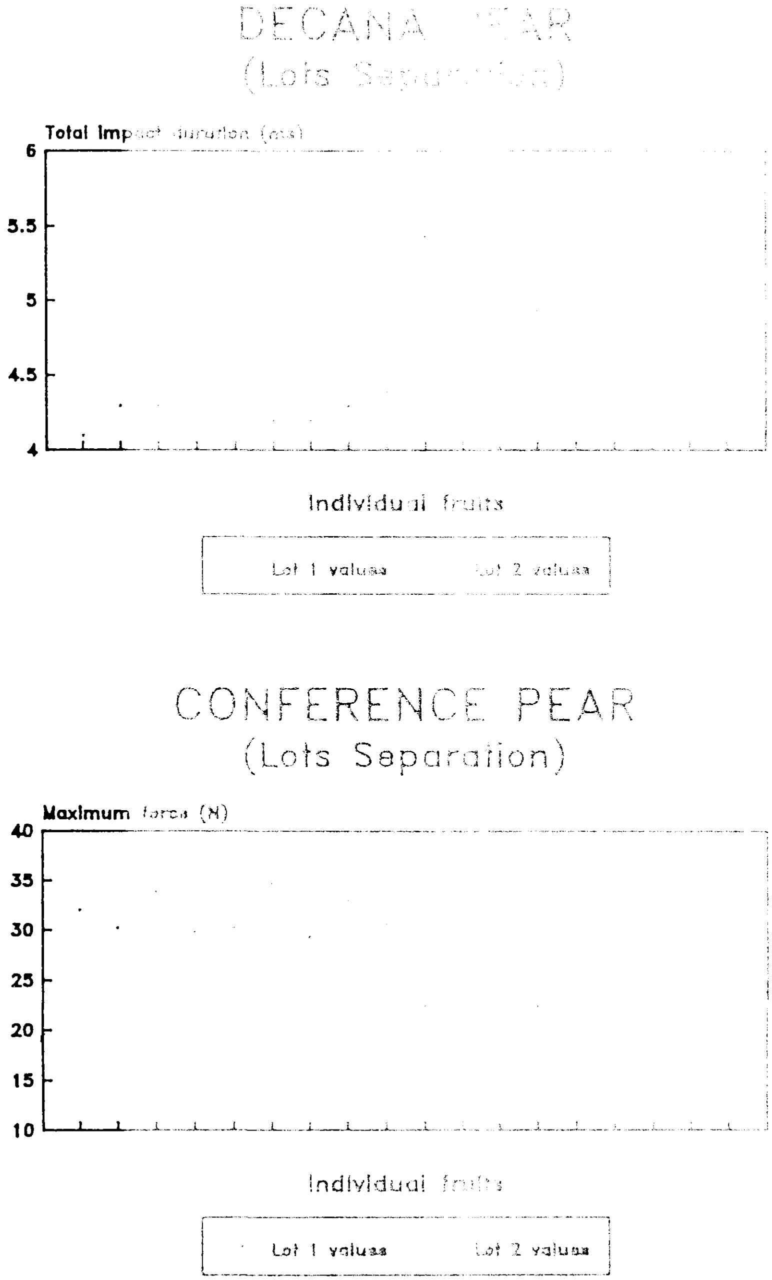


Fig. 2. Impact duration (Decana) and impact force (Conference) for the 10 pears of the training lots. A complete separation of both firmness classes is clearly obtained with just one variable (see then Tables 3 and 4)

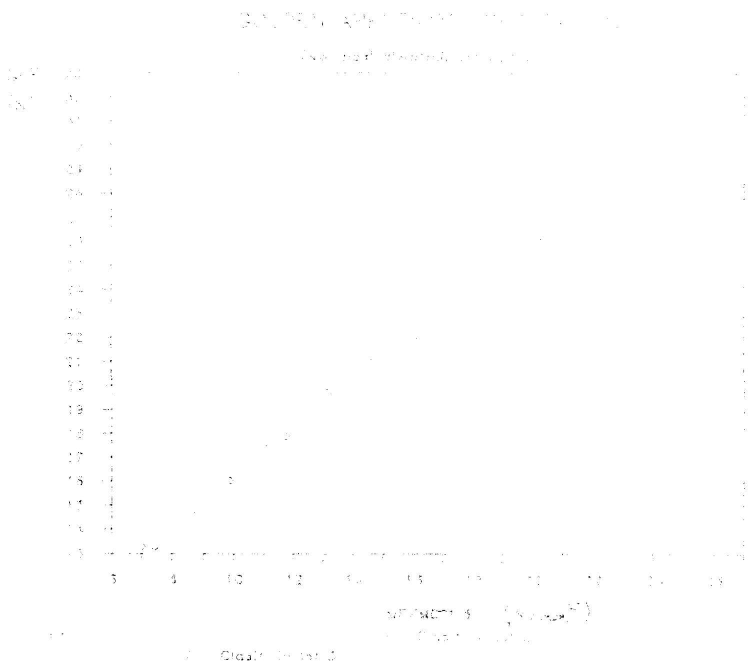


Fig. 3 Distribution of fruits of the training lots for the two most discriminant parameters of their impact response (see Tables 3 and 4), of Golden apples, second test

Figure 2 shows impact duration (ms) and impact force (N) values for Decana and for Conference pear (in both cases, the single variable used in the classification criterion, see Table 3). Both parameters show that there was a very good separation between both groups (accordingly, percentages of correct classification attained in these two cases, Table 4, were very high).

In apples the results were not so good. Golden fruits were well classified in a 60 % and a 70 % (Table 3). Figure 3 shows the distribution of fruits for the two most discriminating parameters (MF and MF/MD^1.5), showing that lots 1 and 2 were partially mixed. For this type of sample, classification errors are bound to appear. Lot 3 was well separated by impact response (Table 3).

The observation of these results suggested some ways for improving the classification procedure. This improvement has been introduced into the software. It is based on a repeated check of the correct separation between lots, two by two, on every step of the calculation of the grading criterium (on every variable introduced).

Granny Smith apples were badly classified by the impact sensor; as shown in other (above referenced) results, this variety shows no significant change in firmness during long periods of postharvest time (up to several [illegible] reflectance data were not useful for this variety, based on some [illegible] foreseen that firmness is not a good potential for ripeness sensing [illegible] Smith apples.

From these results it can be concluded that the system is working [illegible] the aimed objective, that it is consistent and reliable. It is possible to further improve the computational procedure to obtain higher percentages of correctly classified fruits. Integration of both impact and reflectance data is bound to yield optimum classification of these fruits. Further testing of the automatic system and development of the software is being carried out.

3.4. Discussion. Integrating impact and color data for ripeness sensing

Bochereau *et al.* (1992) show that the correlative use of classical methods of data analysis: principal component analysis and regression analysis, can be both used to transform a set of original data (like, for example, impact response parameters or spectral optical data) into first, a set of principal components and secondly applying multiple regression, generating a set of coefficients to create a multiple regression equation. The result of the application of this procedure has been excellent thus far, in accordance with the observations of the cited authors who found "very small" improvements in the prediction by adding [illegible] neural network analysis.

Neural network analysis appears to be very far reaching for the purpose of quality prediction and is being developed further, but also principal components and discriminant analysis give very good results. In our present classification system, not using neural networks, there may be a practical advantage. Considering the likely and unknown variability between fruit batches, this two-phase procedure (I: training and II: actual grading of individual fruits) seems realistic and simple. Moreover it is so by considering the mostly linear nature of the relations obtained until now, and the limitations in the classification needs: usually, only two-three different firmness/ripeness classes may be mixed in an actual fruit batch.

Some kind of previous knowledge is applied for calculating the parameters in the training phase. This saves an immense computational effort. The use of a low number (one to three in most cases) of optimized parameters in the classification criteria can also be fast and simple for on-line application of a ripeness sensing system using impact and color detectors.

4. ACKNOWLEDGEMENTS

The funds for this Project were financed by the CICYT (Spanish Science and Technology Commission). The help of F. García in the classification tests and the analysis of the data and of Prof. P. Chen in reviewing the manuscript are greatly appreciated.

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