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NON-DESTRUCTIVE QUALITY MEASUREMENT AND MODELLING IN FRUITS

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A b s t r a c t. A European Project entitled 'Quality of fruits: Engineering research for improving the quality preservation during pre- and postharvest operations' is being carried out by six European research Institutions. Relevant aspects of quality of fresh fruit in the European market are investigated.

Firmness sensing of selected varieties of apples, pears and avocado fruits has been developed using a non-destructive 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 analysed by three analytical procedures: Principal Components, Correlation, 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 run. Similar procedures were used to analyse the reflectance and colour data. Both sensing systems were able to classify fruits with good accuracy. An automatized prototype of on-line classifier has been built.

K e y w o r d s: fruit, quality, firmness, ripeness, colour

INTRODUCTION

Fruit Quality Engineering: A European Project

During three years, beginning 1992, a Cooperative Contract entitled 'Quality of fruits: Engineering research for improving the quality preservation during pre- and postharvest operations' is being carried out by six relevant European research Institutions: Polytechnical University Madrid, Katholicke Universiteit Leuven, Scottish Centre of Agricultural Engineering, Biotechnological Institute Kolding, Silsoe Research Institute and Cemagref Montpellier.

The objectives of this Project are to develop technical measures to improve quality of fruit by reducing losses due to damage and by improving the techniques for quality grading of fruit. The fruit species studied include apples, pears, peaches and apricots. The actions and activities attained include the following:

1. Information obtained from different fruit markets related to quality reducing damage. Transportation studies. Guidelines have been established for examining fruit samples respective to physical quality.

2. Some techniques are investigated for reducing susceptibility as well as incidence of fruit damage. Some preharvest factors like Ca- and hormone-spraying and irrigation scheduling, postharvest ambient conditions, technical devices for measuring fruit physical properties by impact, compression, skin resistance, and others. Electronic simulated products (SEP) are used in actual grading lines

and new ones are developed with improved capabilities (a static pressure sensing SEP).

3. Sensing devices for determining fruit quality which would be appropriate for on-line measurement are developed: mechanical resonance and impact response for firmness, image analysis for defect recognition, NIR for fruit internal quality assessment.

Non-destructive sensing by impact response and by reflectance

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 [9] and, more recently, mechanical resonance and acoustic impulse techniques [1]. We have found in our previous studies [3,6,8] 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 some of our research activities: the results of firmness classification of different fruit samples of fruits in changing firmness conditions and, classification applications based on reflectance data (VIS) of the same fruits, as they relate to postharvest ripeness and quality.

MATERIALS AND METHODS

Impact response of apples, pears and avocadoes

An impact test was performed using the impact testing system developed by Chen *et al.* [2]. 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.

In a first group of tests, Blanquilla and Decana pears, Golden Delicious and Starking apples, and Hass avocadoes were tested continuously for a period varying between 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 [3,7] were analysed initially by principal components procedures for firmness prediction. As a result, eleven parameters were selected for use as initial input variables of a program for classification based on stepwise discriminant analysis 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 always include two or three 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. Seven batches of apple (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. Fruits were therefore different between batches, and also the (2 or 3) lots per batch were different in firmness.

Reflectance

On each testing date, spectrophotometric measurements were made on samples of 5 fruits using a Perkin-Elmer 555 spectrophotometer with an integrating sphere (pears and apples). 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 derivative of R) were first analysed 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 avocadoes, Hunter parameters L, a, b, C were determined for the skin of samples of 5 fruits at each testing date.

Classification procedure

The classification system works in the following way.

Using ten representative fruits in each group, first training phase is performed. In it, a Quality Index (*QI*) is calculated. This training can be also carried out using data libraries containing response parameters (impact- or reflectance) of any number of fruits previously tested and for which possess the desired properties. All fruits are afterwards classified through the device (working phase), the system using (after sensing each fruit) the classification criterium developed previously in the training phase. Real time is now in the order of 1/100 s.

The analyses included in the classification software are:

1. Principal Component analysis: it is used in the training phase for selection of (usually 11) response parameters which best separate the established groups or classes. It is used also to check on the feasibility of the system for separating those classes (for example, two groups may belong to the same class in reality).

2. Discriminant step by step (linear) regression analysis. The *QI* is established at the end of the training phase, which will be used for classification.

3. Application of the *QI* to every fruit after sensing and asignment to the corresponding class is performed in the working phase on line. The system then performs automatization of fruit deposition.

RESULTS AND DISCUSSION

Firmness sensing by impact response

Impact response variables effective for firmness grading along with optical variables effective for ripeness grading are summarized in Table 1.

Table 2 summarizes the results of all the classification tests carried out so far. Over 2000 fruits have been checked for feasibility of ripeness classification by firmness (impact) and by reflectance in VIS. For example, correct classification (*CC*) of 97 to 100 % of the fruits was obtained when classifying by impact Golden Delicious apples into 3 classes (a time lapse of 10 days of ripeness between classes) and 76 % when grading them into 5 classes.

From these results there are some comments to make: First, the percentage of *CC* fruits is higher when the number of classes is lower. As an example, 100 % or near numbers of *CC* are obtained in the classification of Blanquilla pears into 3 classes, the *QI* using

Table 1. Variables effective for firmness and colour classification of fruits by impact and by optical reflectance; pears, apples, avocadoes [3,5,8]

Impact variables effective for firmness grading	Variables effective for colour/ripeness grading	
(Name, symbol)	Reflectance (pears, apples) R and R' at nm:	Hunter lab parameters (avocadoes)
1. Total duration, TD		
2. Duration to max. force, FD	340^{1}, 380^{2}, 400^{3}, 450^{4},	a (range from unripe to
3. Duration to v=0, TM	460^{5}, 470^{6}, 480^{7}, 500^{8},	overripe: -7 to 1)
4. Increment TD-TM		
5. Max. slope Force/Def., F/T	510^{9}, 530^{10}, 550^{11}, 560^{12},	b (10 to 4.5)
6. Max. slope Force/Time, F/T		
7. Maximum Force, MF	570^{13}, 600^{14}, 620^{15},	$c = a^2 + b^2$
8. Maximum deformation, MD		
9. (F/T)/FD	630^{16}, 660^{17}, 670^{18}, 680^{19},	(12 to 4)
10. Elasticity Modulus EM, or $MD^{3/2}$	690^{20}, 710^{21}, 720^{22}, 730^{23},	
11. Max. shear stress, ss, or $MF/(MD^{3/2})$	760^{24}	

one single impact variable (9, see Table 1) or two reflectance variables (20,16). When classifying into 10 classes, percentages of *CC* are much lower.

Second, as expected, results are very different for different types of fruits and their conditions, varieties, internal variability in the samples, etc., but after all these tests it appears that the procedure is capable of getting high percentages of *CC* fruits in any case, using impact response and reflectance sensing, and selecting the optimal variables in each application.

When changing fruit samples, or changing the number of classes for grading by impact sensing, the first selected variables and the number of them in the *QI* also change. It is difficult to detect from these results any variable that appears most frequently selected and therefore most relevant in the *QI* (except, maybe for 7:MF, and 1:TD). This leads to the conclusion that all these variables are significant for firmness sensing (many more have been studied previously), and the selection by the device of the most discriminating ones, and the classification correctness obtained with them, depends highly on the features of the fruits to be graded. One single variable is not enough for sensing firmness. This is clearly concluded by results obtained by other researchers [4]. In the case of optical reflectance data, further testing is necessary, and possibly some reduction of selected wavelengths (from the ones listed in Table 1) will be found appropriate.

When 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 1 and 2 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 single variable (Table 2). The 90 fruits of Decana pears were well classified in a 85.5 %; their

Table 2. Results of the application of the impact and optical sensing for the grading of fruits [3,5,8,10]

Variety	No. of fruits tested	Treatment	No. of classes	% of fruits correctly classified	No. and type of selected variables	Variables (in the order selected)
Blanquilla pear	60	1st repl.*	5 - 3	76 - 97	- 1 imp.	- 9 (see Table 1)
	110	2nd repl.*	10 - 3	31 - 78	- 5 imp.	- 8,10,5,11,1
	25	same 1st	5 - 3	70 - 100	2 - 7 R **	20,16-20,19,21,14,3,16,5,
		repl.	5 - 3	56 - 100	1 - 5 R'	6-5,20,4,15,9
Decana pear	90	1st repl.	8 - 3	60 - 97	- 4 imp.	- 7,4,2,9
	110	2nd repl.	10 - 3	49 - 92	- 5 imp.	- 2,11,6,3,8
	40	same 1st	8 - 3	62 - 100	3 - 2 R	16,23,21,18,16-18,16
		repl.	8 - 3	82 - 100	6 - 1 R'	21,16,1,10,7,2-16
Golden apple	110	1st repl.	10 - 3	59 - 97	- 3 imp.	- 11,7,4
	110	2nd repl.	10 - 3	40 - 86	- 5 imp.	- 4,11,5,7,1
	50	same 1st	10 - 3	72 - 100	3 - 3 R	1,17,24-1,24,13
		repl.	10 - 3	66 - 100	5 - 4 R'	18,23,12,8,6-18,8,12,23
Starking apple	110	1st repl.	10 - 3	54 - 100	- 4 imp.	- 7,6,8,2
	110	2nd repl.	10 - 3	46 - 92	- 5 imp.	-6,4,10,3,1
	50	same 1st	10 - 3	78 - 100	7 - 2 R	1,21,17,10,20,2,6-1,10
		repl.	10 - 3	50 - 100	3 - 5 R'	20,22,16-18,17,11,16,22
Decana pear	90	cold storage/ room ripening***	2	85.5	1 imp.	1
Conference pear	128	***	2	97.7	1 imp.	7
Golden apple	77	***	3	70.1	9 imp.	11,7,2,5,9,6,10,8,3
Granny-S apple	133	***	3	33.8	3 imp.	6,8,10
Golden apple	121	***	2	60.4	2 imp.	9,3
Granny-S apple	119	***	3	43.7	5 imp.	8,5,4,10,6
Granny-S apple	94	***	3	62.8	3 imp.	4,11,1
Hass avocado	50	20 °C ripening,	4	95	1 imp.	7
		11 days	5	98	1 opt.	A (LAB)
	90	60 storage,	4	87.5	3 imp.	2,1,7
		60 days	4	87.5	3 opt.	H, A, C

* 1st replication: Fruits were tested on the following days after harvest (Sept. 1990). They were allowed to ripen at room temperature until senescence (10/15 days for pears, tests every 2 days; 29 days for apples, tests every 3/4 days). 2nd replication: Fruits were held in cold storage until end of January (1991) and tested in the same way as replication 1; ** R - reflectance values; R' - first derivative of R; *** Lots were obtained, corresponding to n of classes, by storing fruit in cold chamber (4 °C) during a number of days, between 5 and 50, and ripening at 18 °C thereafter. Each varietal lot was tested on the same day [10].

puncture force/deformation (Figs 1 and 2) shows that (at least) two fruits were apparently mixed: it can be guessed that the impact device classified them accordingly into the 'incorrect' lots, and also some bias may have been introduced into 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 Table 2.

Figure 3 shows impact duration (1, Table 1) and impact force (7) values for Decana and for Conference pear (in both cases, the single variable used in the *QI*, see Table 2). Both parameters show that there was a very good separation between both groups as shown by Figs 1 and 2 puncture values.

In apples of this same group of tests the results were not so good. Golden fruits were *CC* in a 60 % and a 70 % (Table 2, lower part). Fig. 3 shows the distribution of fruits for the two most discriminating variables (7:MF and 11:MF/MD ^ 1.5), showing that lots 1 and 2 were partially mixed in the training lots.

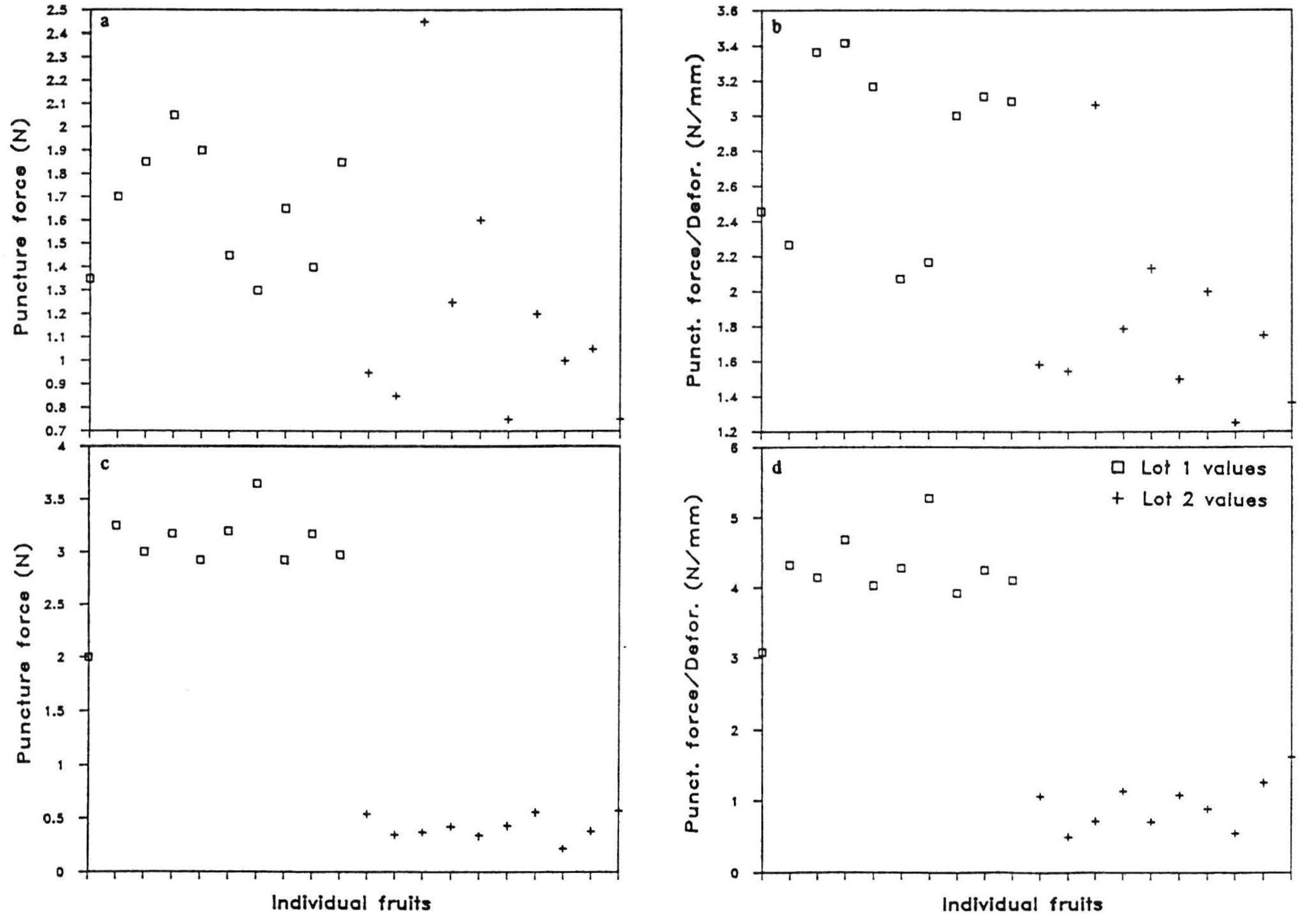

Fig. 1. Puncture resistance: Force at puncture (N) and Force/deformation (N/mm) of the 10 fruits in each lot (training phase) of Decana (a and b) and Conference (c and d) pears. Clear differences between varieties in the relative scatter and the 'distance' between lots are observed.

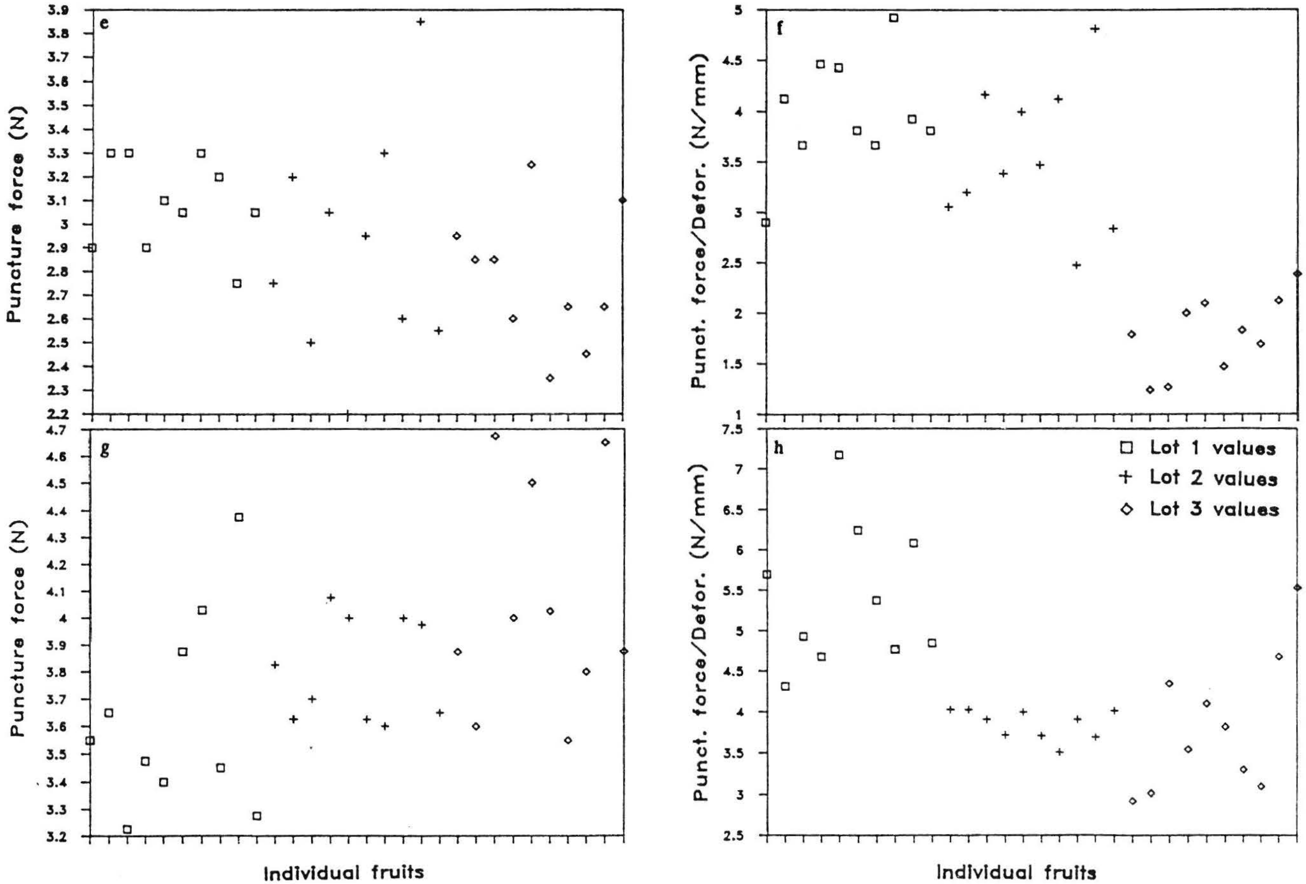

Fig. 2. Puncture resistance: Force at puncture (N) and Force/deformation (N/mm) of the 10 fruits in each lot (training phase) of Golden (e and f) and Granny-Smith (g and h) apples. Clear differences between varieties in the relative scatter and the 'distance' between lots are observed.

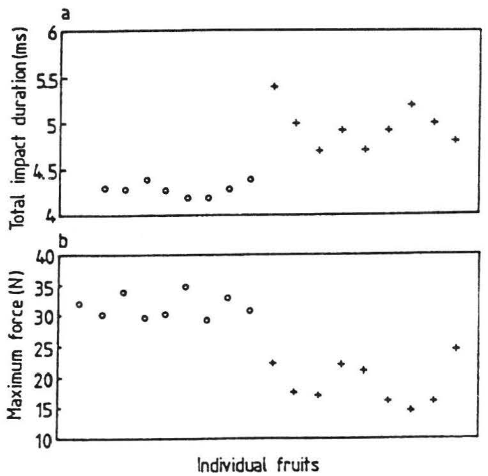

Fig. 3. Impact duration (1:TD, Table 1, Decana pear) and impact force (7:MF, Conference) for the 10+10 pears of the training lots. A complete separation of both firmness classes is clearly obtained with just one variable.

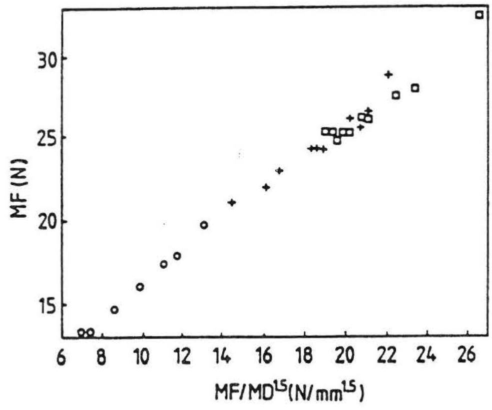

Fig. 4. Distribution of fruits of the training lots for the two most discriminating variables (7:MF and 11:MF/MD ^ 1.5) of Golden apples (121 fruits, Table 1), showing that lots 1 and 2 were partially mixed in the training lots. For this type of samples, classification errors are bound to appear.

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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 *QI* (i.e. 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 months). No reflectance data were available for this variety; based on some observations, it is foreseen that reflectance has good potential for ripeness sensing in Granny Smith apples.

A highly accurate estimation of the firmness evolution of avocadoes 'Hass' was obtained by adjusting a double exponential model [3] of an impact response parameter to days of ripening and to Magness-Taylor firmness values. The obtained models may show further improvement in ripeness sensing. They are now introduced in the coresponding data libraries. This result shows the accuracy of impact response parameters in estimating avocado firmness. Just one or two impact response variables: 7:MF, 2:FD, 1:TD (Table 1) in the referenced data were effective in modelling fruit firmness and in classifying avocadoes into five firmness classes with a 100 % accuracy.

Figure 5 shows the built prototype of a firmness sensor on-line for laboratory tests.

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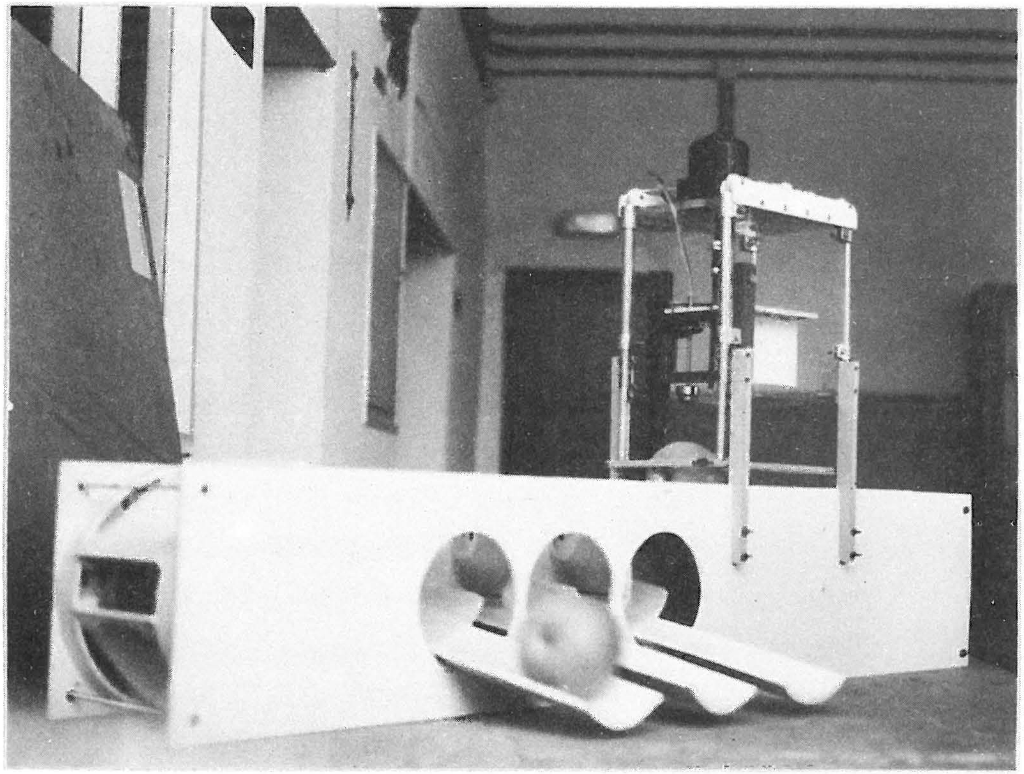

Fig. 5. Prototype of automatic on-line impactor for sensing firmness of fruits.

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