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Segregation of soft olives using Durofel and on-line rebound

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Abstract

Traditional table olive fermentation processing produces variable proportions of defective olives that must be eliminated before final packaging. Defects include fish eye («alambradas»), compact («compactas») and over-ripe olives. For two testing periods during the 2001 season, different batches were graded by size, colour parameters, hardness, density and rebound distance (total number tested was 760 olives). The latter was determined using a specially designed prototype made by an on-line rotating drum covered with a commercial rubber material to avoid damage (13.3 cm total diameter and 6.81 rad s^{-1} rotation speed). Results showed that 96% of measured variance could be explained by the four Principal Components Analysis of extracted factors. Moreover, hardness measured as Durofel-25 units is closely related to rebound distance. Softness thresholds have been addressed for both hardness parameters with devoted logistic models, permitting correct segregation (with 95% of well-classified individuals) of all soft olives (over-ripe and fish eye) using the rebound drum.

Key words: hardness, colour, logistic regression, classification.

Resumen

Separación de aceitunas blandas con Durofel y en línea empleando rebote

La fermentación tradicional de aceitunas de mesa da lugar a la aparición de distintos tipos de defectos, alambradas, compactas y sobremaduras, que hace que las aceitunas defectuosas deban eliminarse antes del empaquetado final. En este estudio, que abarca dos periodos de ensayo en 2001, se han evaluado varios lotes (760 aceitunas en total) que incluyen aceitunas sanas y defectuosas, caracterizándolas objetivamente por calibre, color, dureza, densidad y rebote. Este último parámetro se ha determinado mediante un dispositivo en línea consistente en un cilindro rotativo recubierto con un material amortiguador para evitar daños. Los resultados demuestran que el 96% de la varianza de los datos experimentales puede ser representada mediante cuatro factores principales, y que la firmeza determinada en unidades Durofel está altamente correlacionada con la distancia de rebote. Se han determinado los umbrales de rechazo de aceitunas para ambos parámetros de dureza mediante modelos logísticos, permitiendo separar correctamente de las sanas el 95% de las aceitunas blandas (alambradas y sobremaduras).

Palabras clave: dureza, color, modelo logístico, clasificación.

Introduction

The production system in Portugal for table olives (*Olea europea* L.) relies on traditional fermentation while in Spain large scale controlled fermentation is used (Rejano, 1999). The maturity stage of the olives used in the Spanish procedure has to be closely controlled and homogenised. For this reason, on-line vision systems have been developed (Díaz *et al.*, 2000, 2004).

Traditional fermentation is very popular with consumers demanding high quality and low chemical inputs. This type of consumer associates lower homogeneity of the product, i.e. colour mixture, with more natural production and traditional manufacturers are reluctant to reduce this variability. On the other hand, traditional fermentation may enhance alterations during fermentation which lead to abnormal softening of the olives (Rejano, 1999) especially with a product containing large variability. Occasional abnormal processing leads to defects such as fish-eye (*alambradas*) generating a large

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amount of rejection which in manual classification is difficult and tiring. The introduction of objective on-line measurements is, therefore, of great interest.

The process of «instrumentation», which means the development of instruments, is a complex action that involves all phases: from description of the property, selection of the magnitude and the appropriate test, experiments for calibration, scaling, construction of the prototype, field validation and the definition of threshold values. Some available measurement techniques, such as Durofel, are within a stage of «generalised use» so are considered as *de facto* standards for at-line measurements. On-line measurements are an alternative to at-line tools, where the totality of the product is evaluated one by one with the packing house machinery. Initial on-line classification systems used no electronics as they were based on the possibility of segregating fruits according to their intrinsic characteristics, such as the rebound trajectory. Nowadays, with electronics becoming increasingly accessible, the general scheme used for sensing on-line is composed of: sensor, processor/controller, and actuator, for vision systems, NIR spectrometry or load cells (Barreiro *et al.*, 2004). A simple procedure based on the exploitation of intrinsic properties such as the differences in rebound trajectories may be recommended for on-line performance especially owing to its low implementation cost.

This study was focused on developing an on-line segregation procedure for soft olives based on differences in rebound trajectory already applied to other cases such as potato *versus* clod segregation (Feller *et al.*, 1985, 1987). There was special interest in comparing the performance of this method against other available reference techniques such as at-line mechanical and optical properties and colour measurements.

Material and Methods

Olives cv. Azeiteiro were analysed over two different periods in the 2001 season. In both cases, the material was gathered directly at the output lines of the grading machine of AGRODELTA, a Portuguese manufacturer. With this material, corresponding to three commercial classes, plus the rejected category an assessment was carried out in the University of Evora. Olives (100 fruits per category, 400 in total) were analysed according to size, colour, hardness and density. For the second period, three months later, 360 olives were analysed at the Physical Properties Laboratory (LPF, Madrid) corresponding to six categories (60 olives per category), three commercial classes plus three types of defects identified in the first experiment: over-ripe olives, compact olives (*compactas*) and fish eye olives (*alambradas*). Compact olives and fish eye olives are typical fermentation defects. The former is characterised by shrinkage of the fruit while fish eye olives are easily identified by the presence of blisters. In this experiment, size, colour, hardness and rebound trajectory were quantified.

The size is computed as the number of olives per kilogram based on the individual weight. The colour is measured by means of a visible spectrometer (Minolta C-500), two replicates per olive, and expressed in terms of CIE XYZ and CIE L*a* b* co-ordinates, and the optical reflectance at 670 nm (R670). While the XYZ coordinates express the colour in terms of human perception, L*a*b* represent the objective colour differences, and R670 expresses the amount of chlorophyll present in the fruit (Barreiro *et al.*, 2004). Furthermore, a colour quality index (*i,* Eq. [1]) defined by Rejano (1999) which combines the reflectance at several wavelengths (R_i) was also computed.

$$i = \frac{4R_{635} + R_{590} - 2R_{560}}{3} \quad [1]$$

The hardness is assessed with a Durofel-25 durometer, three replicates per olive, where a spring is compressed onto the fruit and displacement of a tip is measured within a durometer type A instrument (Barreiro *et al.*, 2004). Hardness is expressed as Durofel-25 units (0-100) . The suffix 25 stands for the size of the tip in mm^2 and is chosen from three different ones: 25, 50 and 100. Since no recommendation can be found for olives, the tip selection criterion is based on the recommendation for the most similar fruit, in our case cherries.

The density is estimated by immersing the olives in solutions of increasing salt concentration solutions. Seven solutions from 0 to 3 M NaCl at 23ºC are used and density measured by means of a densometer. Individual olive density is computed as the average between the density of the concentrations corresponding to the boundary solutions for fruit floating and sinking.

The rebound trajectory is assessed using a devoted on-line prototype, designed and mounted at the LPF. This consists of a conveyor set to 0.89 m s^{-1} feed speed, and a rotating cylinder (6.81 rad s^{-1} rotating speed) covered with soft material to avoid damage (Fig. 1). The rebound distance is measured at 0.5 cm steps by means of the mark left by the impact of the olive on a flat surface covered with talcum powder.

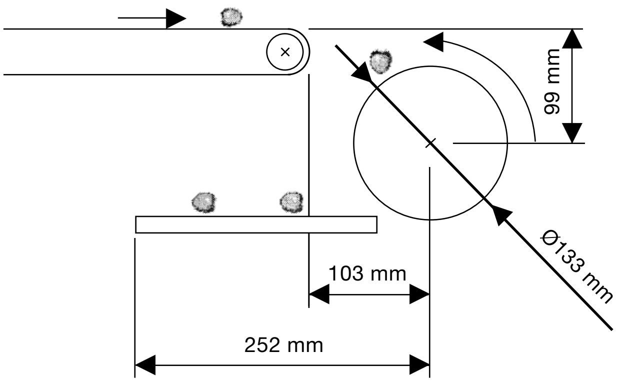

Figure 1. Design of the on-line segregation element based on differences in rebound trajectories.

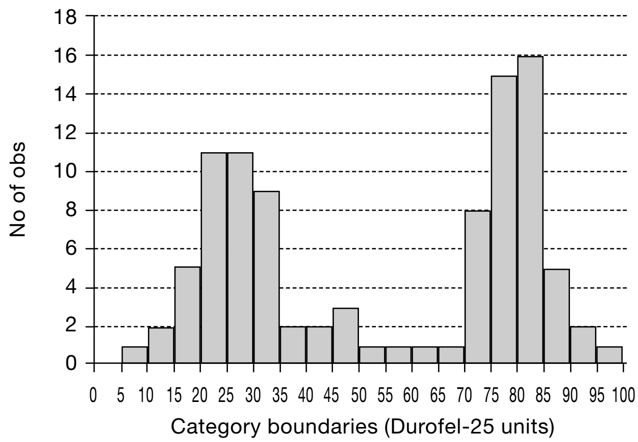

Figure 2. Histogram of rejected samples according to hardness (Durofel-25 units). Three different defects are found in this category: over-ripe and fish eye (*alambradas*) which correspond to extremely soft fruits (mode in the lower hardness range), and compact olives (mode in the upper hardness range). Each bar represents the number of olives within the interval defined by the base of the bar.

The statistical data analysis used for this study consists of a one way analysis of variance of the commercial classes for the reference parameters used in the first experiment (Evora), together with an intra-fruit variability study of these parameters and the maximum difference between individuals. With the data from the second experiment (Madrid), a Principal Components Analysis (PCA) was performed. The experimental variables used for PCA are centred and scaled to unit variance to avoid the magnitude effect. This data pre-processing increases the total experimental variance to the number of variables used in the analysis. The components with an experimental variance above 1 (a single variable) are selected as the most relevant.

Logistic regression is used to predict the individual probability of belonging to the soft categories (over-ripe and fish eye). The rejection threshold is set to a hardness value with probability values above 0.5 of those belonging to soft categories. Classification of olives into accepted/rejected by means of the Durofel-25 threshold is compared to those accepted/rejected using rebound distance threshold, as an indicator of the feasibility of the proposed on-line method.

Results

Table 1 shows the results of the set of olives tested in experiment 1 (Evora), where the main goal was to set up a pool of reference measurements. As expected, significant differences (1% significance level) were found between commercial categories for size, L*, a*, b*, hardness (Durofel-25 units) and density.

Table 1 shows the average hardness (expressed as Durofel-25 units) and the standard deviation for each group, commercial sizes (1 to 3) and the rejected category. A slight decrease in hardness is found for size 1 in comparison with size 3 (smaller fruits). A hardness histogram for the rejected category shows an enormous variability. Its bimodal shape (Fig. 2) points to the presence of two types of defect populations: extremely soft *versus* compact olives. While the latter show a

Table 1. Characterization of the different classes of olives tested in experiment 1

Class ➧	Commercial size 1	Commercial size 2	Commercial size 3	Rejected olives
Size (No. olives kg^{-1})	159 (19)	201 (17)	327 (32)	309 (129)
L*	49.3 (4.8)	50.7 (3.9)	50.9 (3.1)	41.9 (5.3)
a*	8 (3.6)	6.1 (2.5)	5.9 (1.8)	9.5 (3.4)
b*	25.3 (7.1)	27.4 (5.4)	28.1 (3.5)	16 (7.0)
Durofel 25 units	56 (14)	68 (11.7)	79 (6.6)	
Density (g l^{-1})	1,054 (7)	1,057 (7)	1,064 (10)	

Intervals are expressed as mean (standard deviation) for each class.

hardness level equal to or higher than commercial ones, the former correspond to over-ripe and fish eye olives (*alambradas*).

Figure 3 represents all the individuals tested in experiment 1 regarding hardness (Durofel-25 units) and colour (b*). This figure clearly states that not all individuals evolve in the same way for hardness and colour. Two trends are found: horizontal and oblique. The former represents wide colour changes without hardness variation (around 80 Durofel units), while the latter points to a combination of yellow loss (decrease of b*) and softening (decrease of Durofel units). While the horizontal trend is typical for compact olives, the oblique trend corresponds to common physiological evolution for the different ripeness stages.

Table 2 shows that hardness decreases for larger commercial sizes (from 88 to 64 Durofel-25 units), a fact which may be associated with a higher ripeness stage of large fruits. Softening is particularly important for over-ripe olives (average 19 Durofel-25 units). The fish eye olives (*alambradas)* are extremely soft (average 8 Durofel-25 units) but they are also very variable. Thus, an olive with an incipient fish eye defect may show a standard deviation per olive of around 25 Durofel-25 units (data not shown). Table 2 also refers to the results for standard CIE (Commision Internationale de L'Eclairage) colour (L*, a*, b*) and the colour quality index (*i,* Eq. 1). For both b* and **i** values commercial sizes are significantly different to other defective groups.

Table 3 shows some statistical features from the experimental variables tested in experiment 2. Here, the goal is to limit the variability of measurements per olive and not per batch, and also to gather some other complementary information such as the maximum range of variation between extreme olives for each parameter. Size is not included in the table as this was determined once per olive. The standard deviation of each parameter per fruit averaged for the whole set of olives in experiment 2 estimates the precision attained per fruit for each measurement. The error/range ratio, computed as a percentage as the average standard deviation over the range for each parameter, gives an idea of the feasibility of distinguishing between individual fruit and is around 5% for all the variables included in the table.

PCA was carried out using size, rebound distance, hardness, colour quality index *(i),* reflectance at 670 nm, and the colour coordinates X, Y and Z, with all variables centred and scaled to unit variance to avoid the effect of magnitude. The four factors or Principal Components (PCs) extracted include 96% of the total

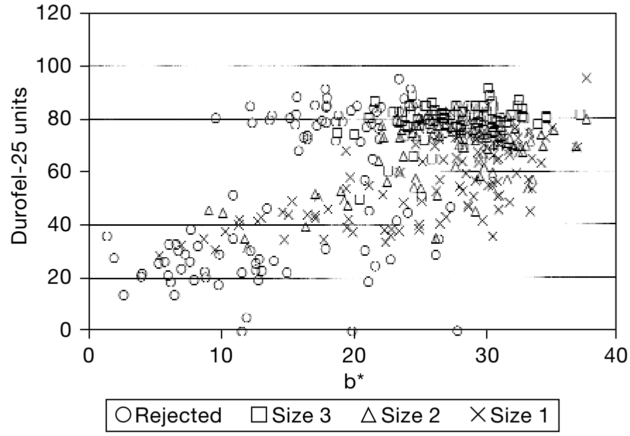

Figure 3. Representation of the average colour (b*) and hardness (Durofel-25 units) per olive. All individuals tested in experiment 1 are shown (N = 400). Two evolution trajectories are found: decreasing yellow and increasing purple (lower b*) together with constant hardness (horizontal trend), and simultaneous yellow and hardness decreasing (oblique trend). The horizontal trend leads to the defect entitled compact olives, while the end of the oblique trend corresponds to over-ripe and fished eye olives.

Table 2. Characterization of the different classes of olives tested in Experiment 2

	Commercial size 1	Commercial size 2	Commercial size 3	Over-ripe olives	Compact olives	Fish eye *(alambradas)*
Size (No. olives kg^{-1})	149 (15)	209 (17)	336 (48)	201 (90)	436 (99)	322 (103)
L*	45.5 (3.4)	47.5 (2.8)	44.6 (3.9)	32.4 (3.2)	36.8 (3.7)	41.2 (5.2)
a*	8.3 (0.8)	8.1 (0.6)	7.6 (0.7)	7.6 (1.5)	6.7 (1.1)	6.2 (1.4)
b*	25.4 (4.6)	27.6 (3.7)	25.1 (3.7)	7.0 (3.2)	15.7 (2.7)	19.7 (5.5)
i value	30.2 (3.0)	32.1 (3.1)	28.6 (4.2)	16.5 (4.4)	18.6 (4.6)	21.6 (5.4)
Durofel 25 units	64 (14)	75 (11)	88 (6)	19 (8)	89 (8)	8 (14)
Rebound distance	20.1 (0.7)	20.2 (0.5)	19.7 (0.7)	17.4 (1.2)	19.4 (0.6)	13.2 (2.7)

Intervals are expressed as mean (standard deviation) for each group. In this experiment, rebound distance (cm) and quality index *i* are measured.

Table 3. Some statistics of the measurements obtained in experiment 2

	Average STD	CV	Minimum	Maximum	Range	Error/range
Distance (cm)	0.533	2.9	9.250	21.500	12.250	4.4
Durofel 25 units	4.958	8.7	0.000	100.000	100.000	5.0
X	0.882	6.8	4.570	22.995	18.425	4.8
Y	0.860	6.8	4.490	22.460	17.970	4.8
Z	0.434	6.5	2.380	9.555	7.175	6.0
L*	1.413	3.4	25.240	54.505	29.265	4.8
a*	0.483	6.5	3.555	10.925	7.370	6.6
b*	1.305	6.5	1.840	36.470	34.630	3.8
R670	1.277	8.7	6.015	31.445	25.430	5.0
i	1.757	7.1	7.730	38.928	31.198	5.6

The average of the intra fruit standard deviation (%) for the whole set of olives (360) refers the precision associated to the measurements per fruit, and is used to compute the coefficient of variation (%) and error/range (%).

variance contained within the original variables. Figure 4 shows the correlation circle for the first and second PCs. The relationship of each original variable with both factors is represented as the proximity to the border of the circle. All the variables except size and R670 are close to the circle border so most of the variability underlying the parameters contained by these variables is explained by them. Factor 1 is highly correlated with the quality index *i* and the colour coordinates X, Y and Z. Factor 2 is strongly correlated with hardness (Durofel-25 units) and the rebound distance (cm), pointing to the feasibility of using rebound as a hardness predictor.

Figure 5 shows the correlation circle using PCs 3 and 4. The reflectance at 670 nm (R670) is correlated with PC3, while the size (nº of olives per kg) relates to PC4, being both orthogonal, so we can conclude that the reflectance at 670 nm contains relevant independent information.

Figures 6 and 7 show two logistic models developed respectively to address either the acceptance threshold for hardness or for Durofel-25 and rebound distance. The procedure described in the previous paragraph is used. In both cases the threshold is set to the magnitude value (Durofel-25 or rebound distance) leading to probability values above 0.5 for those belonging to

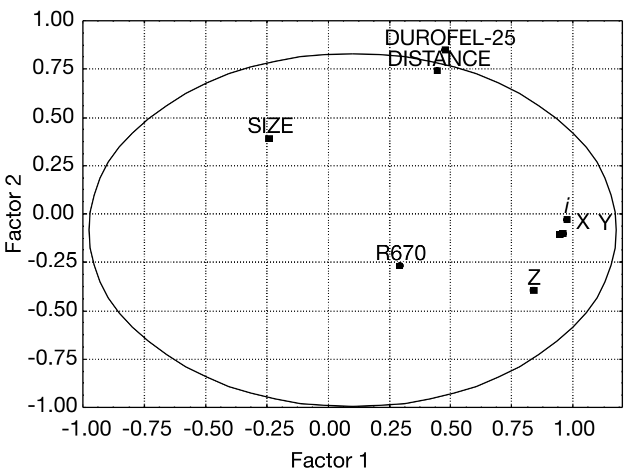

Figure 4. Correlation circle of experimental variables with regard to Principal Components 1 and 2. Measured variables: SIZE, hardness (DUROFEL-25), rebound distance (DISTANCE), colour (X,Y,Z), colour quality index *i* and optical reflectance at 670 nm (R670) are represented on it. Best representation is achieved towards the border of the circle, in this case: DUROFEL-25, DISTANCE, *i,* X, Y, and Z.

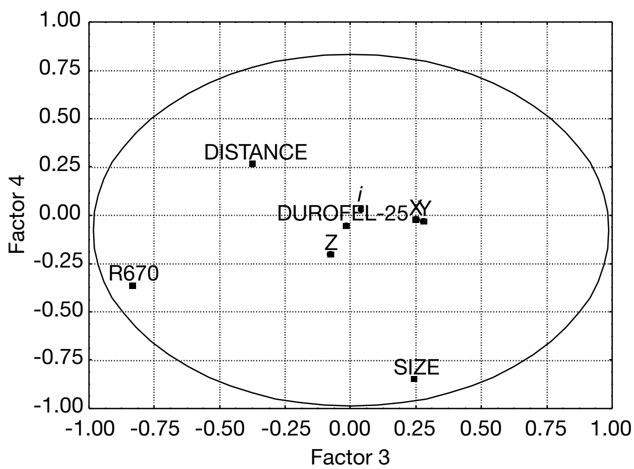

Figure 5. Correlation circle of experimental variables with regard to Principal Components 3 and 4. Measured variables: SIZE, hardness (DUROFEL-25), rebound distance (DISTANCE), colour (X,Y,Z), colour quality index i and optical reflectance at 670 nm (R670) are presented. Best representation is achieved towards the border of the circle, in this case: SIZE, and R670.

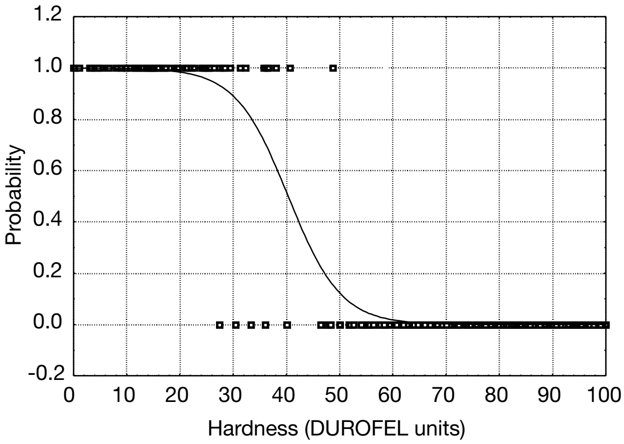

Figure 6. Logistic model (line) for determining the Durofel-25 threshold for extremely soft olives (over-ripe and fish eye). Squares represent measured olives in experiment 2 belonging or not to over-ripe or fish eye category, 1 and 0 probability respectively. Identified threshold (35 units) corresponds to probability above 0.5.

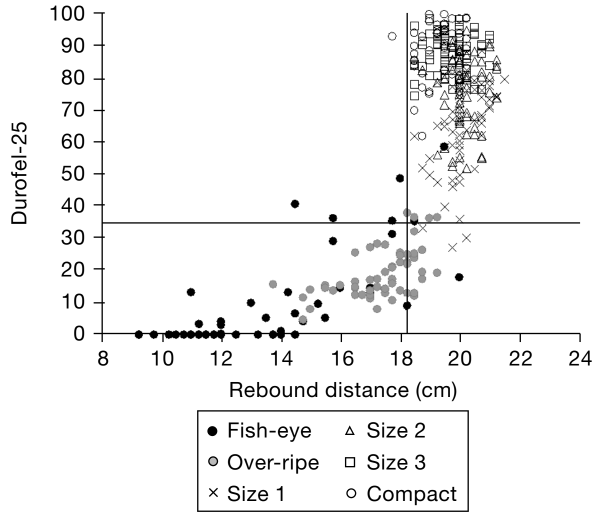

Figure 8. Comparison of Durofel-25 and rebound distance for the identification of soft olives. Individuals are from experiment 2 (N = 360). A 95% agreement is found between both techniques when using the thresholds identified with devoted logistic models.

extremely soft categories (over-ripe and fish eye). Thus, the acceptance threshold corresponds to 35 Durofel-25 units and to 18.25 cm of rebound distance.

Figure 8 compares the performance of Durofel-25 and the rebound segregation system to separate extremely soft olives (over-ripe and fish eye olives). A 95% agreement was found between Durofel-25 and rebound distance for preset threshold values. Only 1.4% (5 out of 360) commercial olives were rejected with this tool without Durofel-25 agreement. Durofel-25 appeared to be very sensitive to hardness differences in the upper range of the scale (50-100 units) in comparison to the rebound distance. However, the latter was more sensitive for softer fruits, showing its best performance for a Durofel-25 range between 0 and 50 units. Compact olives could not be segregated from commercial ones by either Durofel-25 or rebound distance.

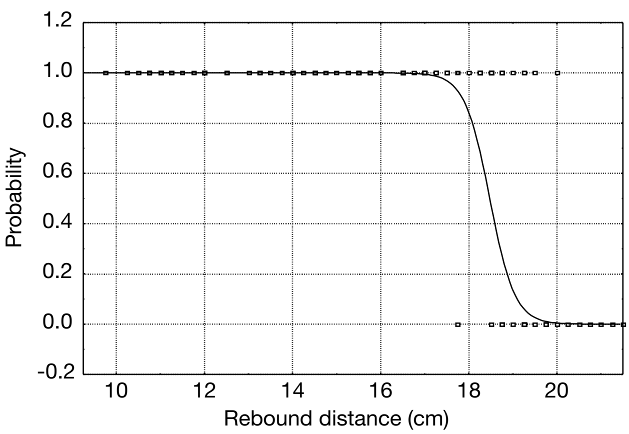

Figure 7. Logistic model (line) for determining the rebound threshold for extremely soft olives (over-ripe and fish eye). Squares represent measured olives in experiment 2 belonging or not to over-ripe or fish eye category, 1 and 0 probability respectively. Identified thresold (18.25 cm) corresponds to probability above 0.5. Note that the resolution of measurement when measuring rebound distance is indicated by the homogeneous distance between squares.

Discussion

Díaz *et al.* (2000) provided colour data for four categories of *manzanilla* olives. The average L*, a* and b* values were similar to those obtained in this study, with L* being around 50, and b* above 20 for commercial olives. Only a* seemed to be different (higher, more red) in our case between 6 and 9 compared to the average of 5 in the aforementioned study. As expected there was higher colour variability in our commercial classes as expected for traditional fermentation. The colour quality index *i* defined by Rejano (1999) for manzanilla olives classified our commercial sizes 1 and 2 as excellent (above 30.2), and commercial size 3 as good (between 26.8 and 30.2).

There is no published data concerning the hardness of olives and so the use of Durofel-25 as a reference is a major issue in this paper. A devoted logistic model allowed us to establish an acceptance threshold for hardness in 35 units under traditional fermentation processing. This threshold has also been confirmed with experts in the production plant.

The proposed on-line method for hardness segregation of olives exploits the differences in rebound distances. As before, an acceptance threshold was established at 18.25 cm by means of a devoted logistic regression model. Extensive external validation has still to be conducted when the online system is available at the production plant.

Major advantages for the proposed online system are a low implementation cost and the feasibility of increasing the work capacity of grading lines under occasional abnormal processing, where the amount of rejected olives is high and manual classification is difficult and tiring.

The work capacity used in this study of 0.3 m s^{-1} allows a classification rate of 100 olives s^{-1} for a 1 m conveyor width. This rate is lower than that reported by vision systems (396 olives s^{-1}, Diaz *et al.*, 2000) although the latter are unable to guarantee the hardness state of the olives without reducing colour variability, which is basic for consumer acceptance in high quality olives under traditional fermentation processing.

Acknowledgements

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