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OPTICAL SYSTEMS TO EVALUATE THE QUALITY OF PRODUCTS

1. INTRODUCTION

The Agricultural Engineering Institute of the University of Milan started its experiences in the application of not destructive technologies for the evaluation of product from the 1993 when was constituted the Hi Tech Group under the leadership of professor Bodria. The principal activity is in the field of the analysis of the maturity stages and quality of agricultural products with some experiences also in the not destructive evaluations of the food products.
These researches are conducted using, especially, optical methods applying these techniques for punctual measurements and for image analysis.

2. THE FRUIT AND VEGETABLES CHARACTERIZATION

During ripening a fruit or vegetable undergoes several concurrent and sequential biochemical processes that deeply transform its properties. These changes affect the quality attributes in terms of: texture and firmness (due to solubilization of pectin); flavour (due to: starch conversion into sugars; changes in organic acid content; production of aromatic volatiles); colour appearance (due to: chlorophyll degradation in the skin; synthesis and/or unmasking of carotenoids and anthocyanins).
These biological phenomenon are the basis of all the researches which use different physical approaches with the common aim to characterised the agricultural products in terms of quality or ripeness with non destructive methods.
The validation of these systems is obtained comparing the data from the experimental set-ups with those from conventional destructive methods (firmness, content of soluble solids, chlorophyll content) or from colour measurements using a colorimeter.

3. PUNCTUAL MEASUREMENTS

The punctual measurements permit to characterised the products only in a particularly region giving very interesting data about the sugar content and the maturity stage.

3.1 Dual-band reflectance measurements

The aim of this experimentation is to design a device for in field measurements so that the operator could follow the ripeness of fruit again in the orchard.

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The experimental set-up for the pointwise measurement (fig.1) use the red and near-infrared bands and consist of:

- a 10 mW laser diode which emits monochromatic light at a wavelength of 675 nm and a pair of LEDs emitting at 800 nm, which sequentially illuminate the portion of the fruit being analysed;
- two photodiodes, integrated into the system, which collect and measure the light reflected by the fruit when illuminated by the two types of sources;
- one computer for the acquisition and storage of the measured data.

The testing of the method involved resting the probe directly on the equatorial region of the fruit, and then manually triggering the PC to acquire the reflectance value obtained under illumination with the laser and the LEDs.

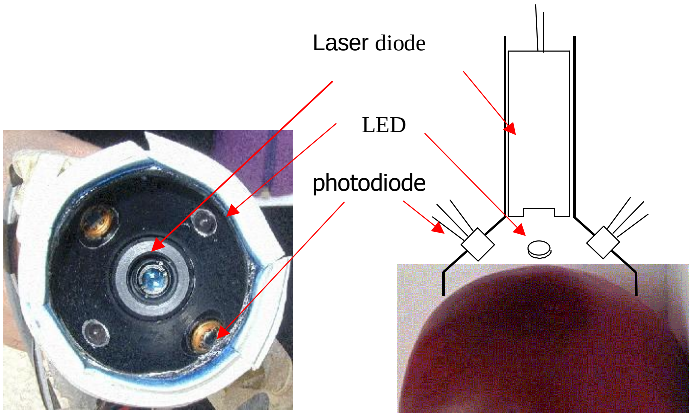
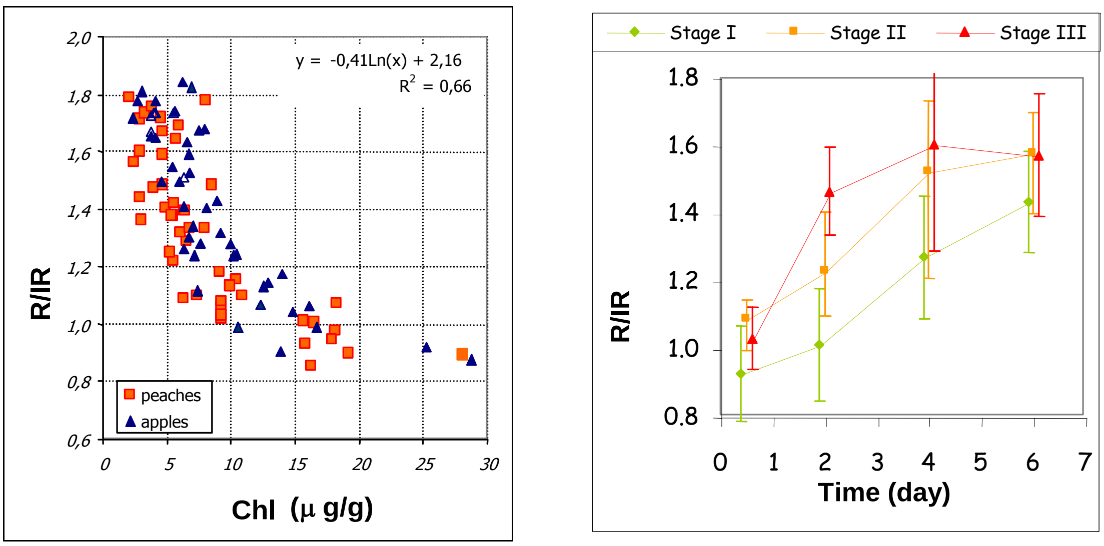


Fig.1 – System for punctual two bands reflectance

The tests with the set-up for pointwise reflectance measurement, conducted using peaches (*cv Summer Rich*), nectarines (*cv Big Top*) and apples (*cv Red Delicious)*, led to the determination of an *R/IR* index, which is the ratio between reflectance in the red band at 675 nm (*R*) and reflectance in the infrared band at 800 nm (*IR*). Because this index is a ratio between two measured values, it is unaffected by the geometry of the reflectance measurement. In particular, this index was found to successfully predict the chlorophyll content with a good accuracy (R^2 = 0.6 – 0.7 depending on the cultivar analysed, fig.2a). Some of the tests were carried out in such a way as to follow the



a) b)

Fig.2 – a) R/IR index vs chlorophyll content; b) behaviour of R/IR index during post-harvest days.

development of fruit harvested at different stages of maturity and opportunely graded by experts. Using the reflectance measurements and the *R/IR* index, it was possible to track the ripening of the fruits even in the absence of significant variations in colour (fig.2b). The test showed how the slope of the fruit maturation curve changes as a function of the initial state: the ripest fruits have a steeper slope at the beginning, which indicates rapid degradation of the chlorophyll; the more unripe fruits, on the other hand, have a curve with a lower slope, reflecting slower degradation of the chlorophyll. In both cases, however, the same ratio is reached (*R/IR* > 1.4) at the end of the monitored period (6 days), indicating that maturation is complete.

3.2 NIR techniques

The spectral data are one of the most important source of information to know the organoleptic properties of fruit and vegetables. With this aims, an experimental device, based on a VIS-NIR spectrometer, was designed and realised to collect the spectrum without any part in contact with the products and so to work on line, where the products have to have particularly orientation.

The aim of the research is to develop some spectral algorithms to evaluate the sugar content with a limited number of wavelengths. In some cases is studied the possibility of predicting also the firmness and the acidity, but the experimental phases are going on again.

The device used for these studies is constituted by:

- a dark chamber, to avoid the interference of the external light, with three halogen lamps powered by 50 W, situated in the same plan in an orthogonal way, to illuminate three faces of the products; in the free late (the fourth of the chamber) there is the optical fibre to collect the light through the fruit and transferred it to the spectrometer;
- a spectrometer, working in the interval between 550 and 1100 nm, which need to acquire the spectrum of a time of 150 ms;
- a PC, to acquire and stored the spectrums and to menage the spectrometer.

The spectrums are transformed to eliminate the disturbs of the measurements and avoid the not significant informations.

The spectral data and the reference values obtained by the classical destructive methods, are inserted in the data-table of the statistical programme Unscrambler to elaborate the calibration models, with the use of the second derivative of the transmittance value, like independent data, in the regression and the destructive value, like dependent data. The derivative spectrum conserved the peak' positions, removing the additive effects in the spectra, and permit to underline the variation of the spectra data due to the soluble solid content of the fruit.

The regression, between spectra and organoleptic data, is calculated with the techniques of the Partial Last Squares (PLS), a very circulated method for the statistical multivariate analysis of a high number of independent variables. The equation is, then, applied to predict the values on a set of fruit which aren't used in the calibration phase.

Besides, the most interesting intervals of wavelengths for the calibrations in the PLS, are used for another regression: the multilinear regression (MLR). With this algorithm is investigated the possibilities to use a simpler model, but always reliability, than the one by the PLS.

The experimentation was conducted on kiwi, apples and oranges. In every case the results show a good correlation between the Brix grade obtained with the destructive methods and the predictions by NIR.

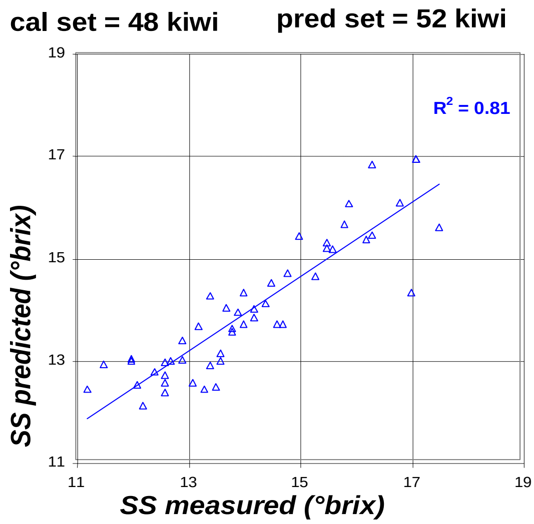


Fig.3 - Predicted SS vs measured SS for Kiwi (cv Hayward)

Kiwi (cv Hayward)
The PLS model obtained good correlation (R^2 = 0,86) between the destructive values and the predicted ones, while the Standard Error of Calibration (SEC) is about 0,5 °Brix. In prediction, with another set of fruit, there is always a discrete correlation (R^2 = 0,53) with a Standard Error of Prediction (SEP) of 1,0 °Brix.
The MLR obtained comparable results: in calibration the correlation was good with a coefficient of R^2 = 0,86 and a SEC of 0,6°Brix, while in prediction the coefficients became 0,63 and 0,9 °Brix.

Orange (cv Navel and Tarocco)
The study was developed in two years using *cv Navel* and *cv Tarocco*. The model is the result of the joint of both the data. The PLS model obtained, in calibration, a good correlation (R^2 = 0,88) and a SEC of 0,48° Brix, while in prediction the results are R^2 =

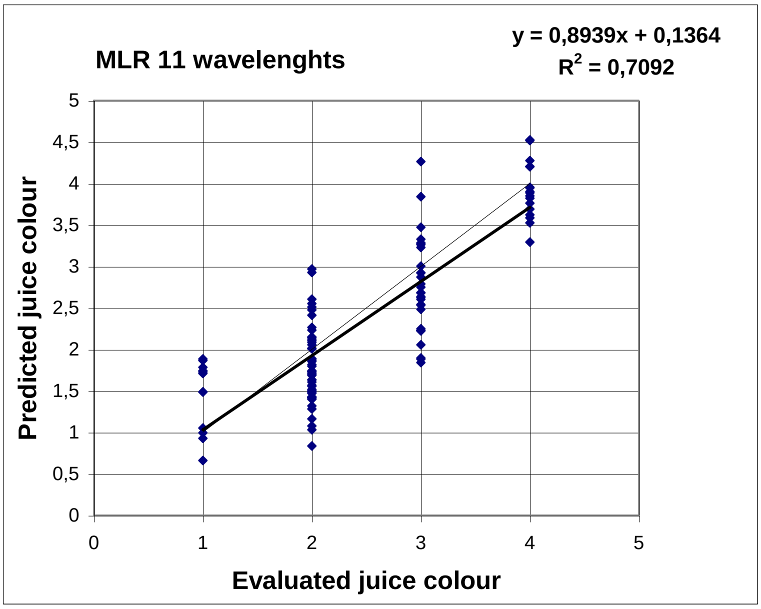


Fig.4 - Predicted colour vs estimated colour for oranges juice (cv Navel and Tarocco)

0,58 and SEP = 0,65 ° Brix. Also MLR analysis was conducted: in calibration it was obtained R^2 = 0,87 and SEC = 0,50 while during the prediction phase R^2 = 0,53 and SEP = 0,73°Brix.
The study was extended to the prediction of the colour of the juice (fig.4): the PLS prediction obtained a R^2 = 0,79 and a SEP = 0,41 showing like the spectrum analysis contained also this information.

Apples
The study is working on to evaluate the influence of the position of the fruit respect the lights and the direction of the axis of the fruit. The first results, showed in the table 1 in term of predictions, display that the most interesting position in the dark chamber is with axis in the horizontal position with two lights (R^2 = 0,72, SEP = 0,65 ° Brix).

Table.1 - Effect of the position of the apple on the R^2 and SEP during NIR prediction.

Apple position	***R^2***	***SEP***
Vertical, 3 lamps	0,407	0,89
Vertical, 2 lamps	0,302	0,94
Horizontal, 3 lamps	0,504	0,85
Horizontal, 2 lamps	0,722	0,65

3.3 Strawberries brightness
The strawberries are a very delicate and particular fruit so that it isn't used the recently indices for the agricultural products (colour, NIR analysis, ecc.) but the interest of the operators is about the brightness, because the fruit which have a surface particularly bright seem to have a longer shelf life.
The aim of this study is to design a simple device to evaluate the brightness of single strawberry. The experimental set is composed by:

- a light source constituted by a laser with a wavelength of 635 nm and an ocular that can open the pencil of light till 20 mm;
- a photodiode with a biconvex lens to focalise the reflected ray in the sensible part of the photodiode to have a better tension signal;
- two supporter arm (one for the laser and the other for the photodiode) mounted on a goniometer to have the exact incident and reflection angles;
- a vertical mobile plan to obtained the perfect condition of mirror reflection.

The experimentation of the set regarded about one thousand strawberries both fresh and refrigerated, which are correctly divided by experts in two classes where the level of quality are proportional to the level of brightness.

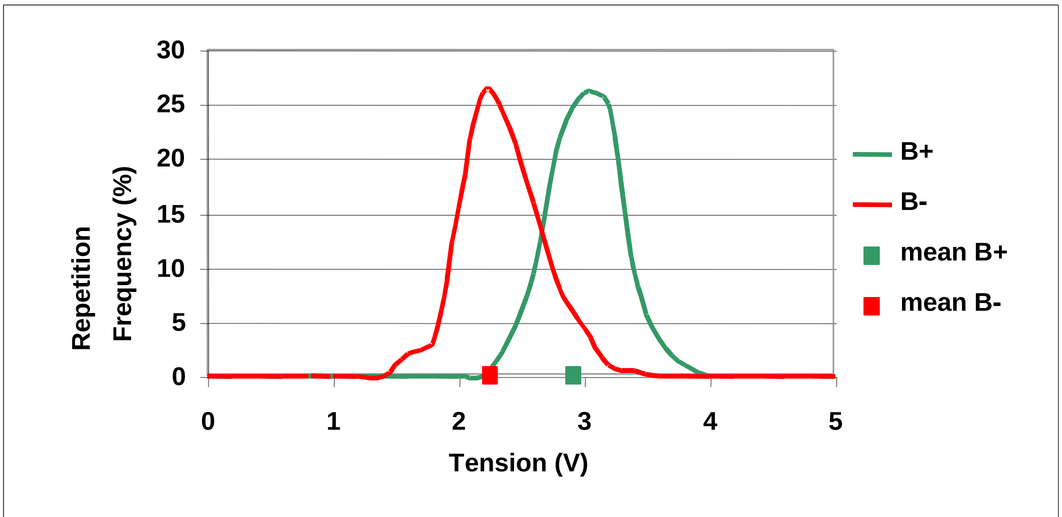


Fig.5 - Identification of the two classes of strawberries: the more bright (B+) and the less one (B-)

The results show that the device can distinguish the two classes (fig.5) giving to the more bright class the higher value of tension The differences between the medium value of the two classes is of 0,35 V for the fresh strawberries and 0,6 V for the refrigerated strawberries.

This results indicated like this method could be interesting both to develop a simple device and to suggest the possibilities to use also image analysis.

4. IMAGE ANALYSIS

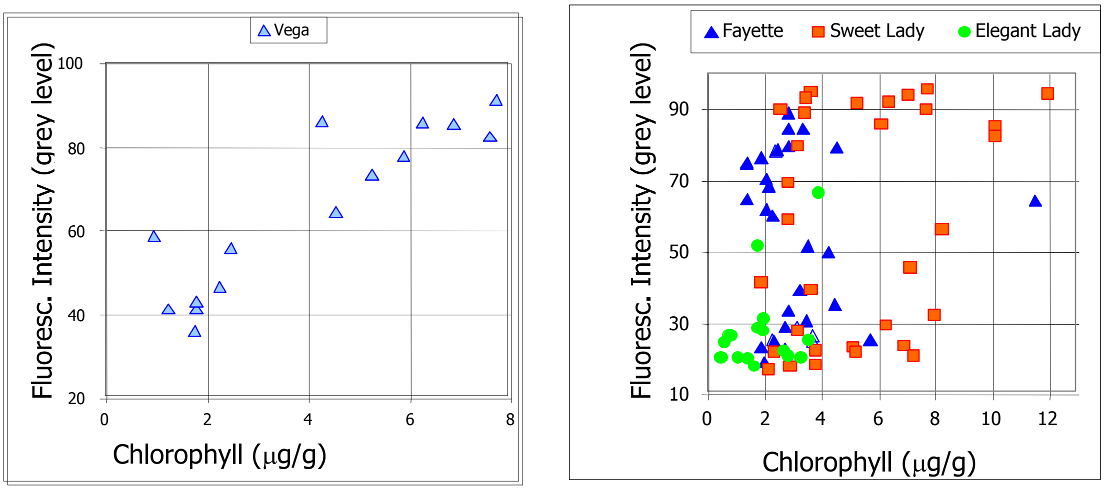
The image analysis use cameras to detect the characterisation of the superficial level of the agricultural products. Using special filters it is possible to have also images from the not visible part of the spectrum, which can show particular properties of the fruit.

4.1 Fluorescence images

Among the various parameters that undergo measurable changes during the fruit maturation process, the degradation of chlorophyll - responsible for the loss of green colouring from the skin of many fruits - is an important element for characterising the stage of fruit maturity. What's more, the possibility of determining the chlorophyll content through fluorescence measurements makes this an extremely interesting index for determining the stage of maturity of the products.
The experimental set-up for the measurement of fluorescence consisted of the following elements:

- one dark chamber equipped with a light source for the excitation of fluorescence and with the various components assembled inside, including a height-adjustable support on which the sample fruit is placed;
- one CCD camera equipped with an RG-695 high-pass filter which transmits only radiation having wavelengths greater than 690 nm; this camera is connected to a frame grabber (Date Translation DT 3155) which digitises the images and stores them on the hard disk of the PC controller, ready for subsequent analysis by a special software program.

Two different systems were used for illuminating the fruit: one with a *blue light source*, consisting of two 600 W ULTRAMED mercury lamps for illuminating the fruit and a BG-40 low-pass filter that transmits only radiation having wavelengths of less than 600 nm, equipped with a manually operated diaphragm for controlling the exposure time of the fruit to the light beam; a second *red light* system in which an illuminator, consisting of a series of "ultra-bright" type LEDs mounted on a dome shaped support, emits red light at 650-680 nm.
During the testing the fruit was placed inside the dark chamber and the resulting fluorescence image captured by the camera was analysed to quantify the pixel intensity (greyscale level) in the equatorial region of the fruit, which is the part that best indicates the stage of maturity. In particular, the system for fluorescence image analysis under blue light was tested on apricots (*cv San Castrese*) and apples (*cv Red delicious*), obtaining a good correlation with the sugar content and hardness values determined by destructive methods, with a correlation index R^2 = 0.81 between the measured fluorescence and hardness for apples (Guidetti and Oberti, 1998), The tests on peaches (*cv Vega*, *Max*, *Fayette*, *Sweet lady*, *Elegant lady*) exhibited a high dependence of the method on the variety of fruit: whereas with the *Vega cultivar* there was a good correlation between the fluorescence value and the chlorophyll content in the epidermis

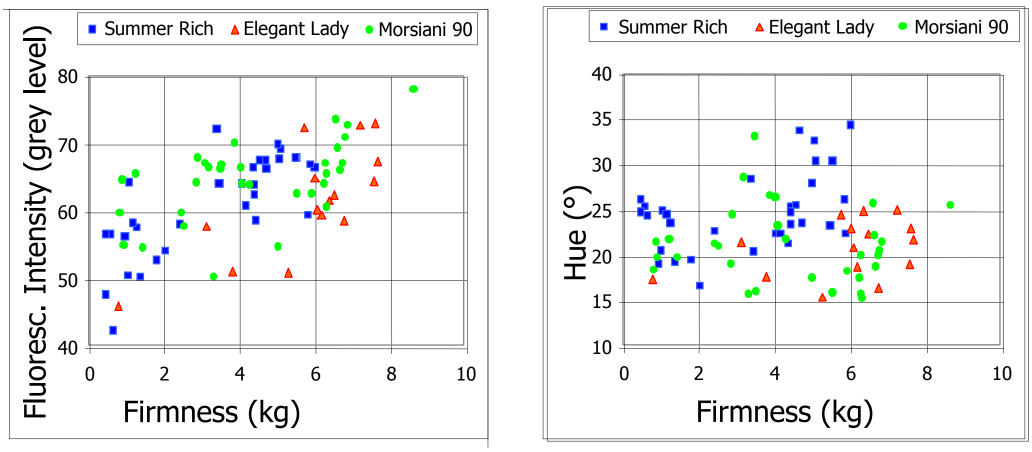


a) b)

Fig. 6 *– Fluorescence intensity vs chlorophyll content using the blue system: a) Vega cultivar; b) Fayette and Elegant lady cultivars.*

of the fruit (fig.6.a), for the other cultivars the results were, on the contrary, very scattered (fig.6.b).

The tests under a red LED light source were conducted on peaches (*cv Elegant lady, Summer Rich, Max, Royal Gem*) and nectarines (*cv Morisani 90*), with results that - despite exhibiting a consistent trend (fig.7.a) between destructive and non-destructive measurements - are only partially satisfactory for the classification of the fruits, although they still provide a more reliable indication than colour alone (fig.7.b).



a) b)

Fig.7 *– a) Fluorescence intensity vs firmness and b) Hue vs firmness: it is clear the good correlation in the diagram a) and the absence, in diagram b).*

4.2 Reflectance images

The reflectance analysis evaluate the reflex ray coming from a sample with a right light. Particularly filters permit to obtain also superficial information like bruises and other injuries to classify the products and to automatize the sorting.

The focus of this research is on the possibilities to reveal the presence of bruises on the product by mechanical operation during or post the harvest, or by the developing of

pathogens, like penicillium, during the ripening. The reflectance images are used also to detect the brightness of the strawberries.
The experimental set is composed by a digital camera with or without a monochromator, constituted by a motorised wheel, controlled by a PC, with eighteen filters in the interval between 380 and 1060 nm.

Detection of bruises
The experimentation regarded especially apples (*cv Golden Delicious*), peers (*cv Decana*) and peaches (*cv Elegant Lady*). The data analysis permit to develop a multispectral method to identify the two more significant wavelengths: to recognised the whole region of the fruit from that pathological one or with a mechanical damage; to combine the information from the two images of the fruit at the two wavelengths identified, and from them to obtain an another "virtual" image in which the injuries are more visible and potentially recognisable from an automatic system. This possibility has to be possible especially for very early injuries.
In the "virtual" images obtained after 24 hours for the mechanical bruises, or after 48 hours for the pathological ones, the interested regions result well defined with a good contrast while, visually, they are identifiable, only with a very carefully observation.

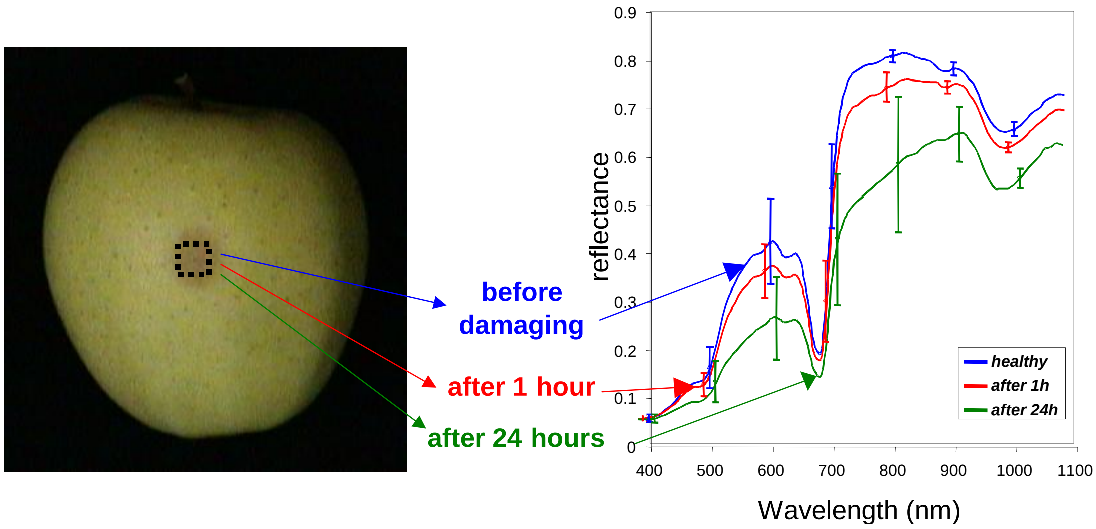


Fig.8 - Mechanical bruise region in an apple and relative variation of the spectrum

For the mechanical bruises, studied on peers and apples, the more significant spectral couples is formed by 440 nm and 600 nm for peers and 520 and 820 for the apples (fig.8), while the pathological bruises, analysed on the peaches, are well identify in the image obtained directly at 440 nm (fig.9) and the multispectral analysis doesn't supply interesting results.

Strawberries brightness
To develop the previous studies about the brightness is examine closely the mirror reflection and the possibility to use the polarised light. The objective of this study is to arrive to have an index to classify a whole strawberries box.

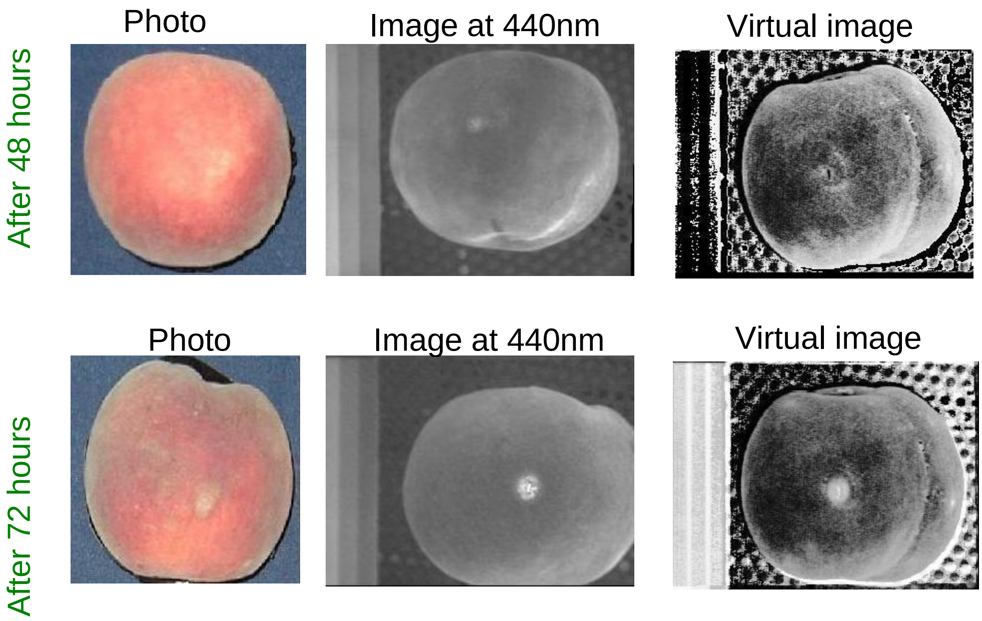


Fig.9 - Identification of the pathological bruises with the image at 440 nm. The virtual image is obtained with the ratio of the image at 480 nm and 700 nm.

The device used for the research is composed by:

- an halogens light (50 W);
- an acquisition image system formed by a camera and a polarised filter which can rotate on its axis.

With this method it is possible having three image (fig.10): one without the filter, the second one with the polar axis of the filter parallel to the plan of oscillation of the reflected waves, the third one with the polar axis orthogonal to the plan of the oscillation of the reflected waves.

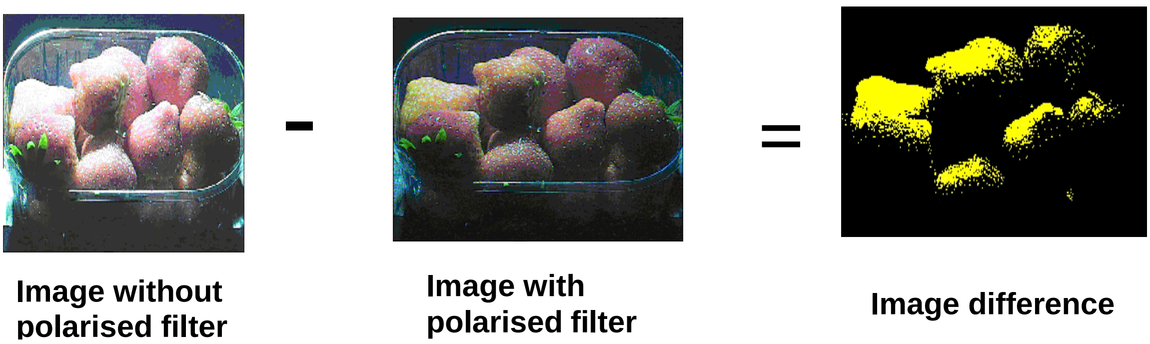


Fig.10 - Three images used to obtain a brightness index (IB) to sorting the strawberries basket for brightness.

The analysis of this three images permits to obtain a brightness index (IB) to separate strawberries which different quality level, given from the ratio between the part of the image which show reflection and the one which doesn't reflect.

5. Conclusions

Providing the consumer with high quality fruit and vegetables is a complex, multi-disciplinary task that requires agronomical, bio-physiological, technological and modelling contributions. In this regard, one of the most important aspects in which engineering is directly involved concerns the development of methods and instruments for the non-destructive measurement of the physical-chemical properties of the product, and the definition of appropriate relationships with their evolution and specific threshold values.

The researches conducted in the Agricultural Engineering Institute of the University of Milan, show that the physical principles can give right indication about the quality level and ripeness stage of fruit and vegetables. The objective to design low cost and user friendly devices is now within reach. The researches are now ready to involved closely the industrial word and try to realise:

- the increase of the performance of the on line machine with the aim to have a reliable sorting with more products: this means the generalisation of some algorithm to can predict the products characteristics;
- the develop of device very precise for the use of many parameters (sugar content, acidity, nutritional elements, etc.) detecting from the spectral analysis; the use of this device could be dual: it could be a supporter to the agronomic selection and validation and also it could be an help for the consumer that could sort directly the products closely to his own taste.
- an improvement of the device for the standard measurements: e.g. a not destructive refractometer.

References

Beaudry, R. M., A. N Mir, J. Song, P. Armstrong, W. Deng, and E. Timm, 1997. Chlorophyll fluorescence: A non-destructive tool for quality measurements of stored apple fruit. In *Proc. Sensors for Non-Destructive Testing International Conf*., 56-65. J. Abbot et al., eds. Ithaca, N.Y.: Northeast Regional Agricultural Engineering Service.

Delwiche, M. J., S. Tang, and J. W. Rumsey. 1987. Color and optical properties of clingstone peaches related to maturity. *Trans. ASAE* 30(6): 1873-1879.

Eccher Zerbini, P., F. Gorini, G. L. Spada, and C. Liverani. 1991. Peaches ground color as an index for the harvest date (in Italian). *Frutticoltura* 53(6): 27-33.

Guidetti, R., I. Mignani, and R. Oberti. 1998. Image analysis for evaluation of fruit quality: Measurement of fluorescence as an indicator of maturity stage (in Italian). *Italus Hortus* 5(6): 23-26.

Kempler, C., J. Kabaluk, and P. Toivonen. 1992. Effect of environment and harvest date on maturation and ripening of kiwifruit in British Columbia. *Canadian J. Plant Science* 72(3): 863-869.

Lavrijnsen, P., and O. Van Kooten. 1993. Chlorophyll fluorescence as a possible aid to determine the ripeness stage in apples. Wageningen, The Netherlands: ATO-DLO Reports.

Li, M., D. C. Slaughter, and J. F. Thompson. 1997. Optical chlorophyll sensing system for banana ripening. *Postharvest Biol. and Tech.* 12(3): 273-283.

Merzlyak, M. N., A. A. Gitelson, O. B. Chivkunova, and V. Y. Rakitin. 1999. Non-destructive optical detection of pigment changes during leaf senescence and fruit ripening. *Physiol. Plant* 106(1): 135-141.

Merzlyak, M. N., A. E. Solovchenko, and A. A. Gitelson. 2003. Reflectance spectral features and non-destructive estimation of chlorophyll, carotenoid, and anthocyanin content in apple fruit. *Postharvest Biol. and Tech.* 27(2): 197-211.

Mir, A. N., R. Perez, and R. M. Beaudry. 1998. Chlorophyll fluorescence and whole fruit senescence in 'Golden Delicious' apple. *Acta Horticulturae* 464: 121-126.

Nedbal, L., J. Soukupova, J. Whitmarsh, and M. Trtilek. 2000. Postharvest imaging of chlorophyll fluorescence from lemons can be used to predict fruit quality. *Photosynthetica* 38(4): 571-579.

Porra, R. J., W. A. Thompson, and P. E. Kriedemann. 1989. Determination of accurate extinction coefficients and simultaneous equations for assaying chlorophylls a and b extracted with four different solvents: verification of the concentration of chlorophyll standards by atomic absorption spectroscopy. *Biochimica and Biophysica Acta* 975: 384-394.

Ruiz-Altissent, M., L. Lleò, and F. Riquelme. 2000. Instrumental quality assessment of fresh peaches: Optical and mechanical parameters. In *Proc. International Conference in Agriculture Engineering*. Paper 00-PH-005. Warwick, U.K.: AgEng 2000.

Slaughter, D. C. 1995. Nondestructive determination of internal quality in peaches and nectarines. *Trans. ASAE* 38(2): 617-623.

Zude-Sasse, M., I. Truppel, and B. Herold. 2002. An approach to non-destructive apple fruit chlorophyll determination. *Postharvest Biol. and Tech.* 25(2): 123-133.