Using NIRS spectroscopy to predict postharvest quality

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Abstract

The nutritional importance of fruits and vegetables, and the purpose of assuring their acceptance, encourages developing technology to monitor their quality attributes during postharvest. The near-infrared spectroscopy offers great potential to achieve these purposes. In this paper we review more relevant aspects of the use of this technology for the prediction of postharvest quality parameters. The aspects of quality that can be measured by NIRS, its evolution, research on different products, and most outstanding areas for action, are highlighted.

Keywords: NIRS, postharvest, quality, fruit, vegetable

Review Methodology: FSTA, AGRIS and SCOPUS data bases was used.

The problem and ability

The quality evolution during postharvest life, that concerns all plant foods, is particularly important in perishable goods. Thus, 'postharvest' refers normally to fresh commodities, like fruits and vegetables. These produce comprise a complex of activities that characterize it as the most important sector of agriculture in many countries, within areas of temperate and warm climates. Also, there is a growing appreciation of the nutritional importance of fruits and vegetables for its vitamins, dietary fiber, antioxidants, and phytochemicals with beneficial biological activities [1].

Ensuring a minimum level of consumer acceptance of these commodities requires assessing its internal quality by techniques swift and non-destructive. Simplification of analysis and possibility of monitor much of the commodity in real time, also are important targets. The improvement of environmental sustainability of human activities also is a current challenge. Analytical techniques nondestructive can contribute to this need since it does not require chemical reagents or solvents, no waste producing.

Nondestructive techniques for fruit quality analysis might be interesting at various stages of the production chain. The first relates to the pre-harvest. The ability to monitor, or instantly analyze, the parameters of fruit quality in field can be a big advantage to develop strategies for harvesting. The sample transport and laboratory analysis are avoided, thus is saved time and money. The next stage is the handling and packing at fruit pack-houses, where automatic fruit sorting according with certain quality parameters is a very interesting application. Another stage is the food distribution chain. At this phase, distributors and consumers are interested on verify easily and quickly that the product acquired meets the desired characteristics. This option could bring transparency to the marketing and competitiveness at the price formation process. By these reasons, there is great interest currently on fruit quality analysis nondestructive. A recognized expert in post-harvest said: ‘Future research and development efforts should focus on developing better methods of monitoring quality and safety attributes of fresh produces as part of a quality assurance system' [2].

Few studies there are aimed to determinate the best non-destructive technique for analyzing a fruit quality parameter, considering the required accuracy and its cost. Searching in databases highlights clearly the use of near infrared spectroscopy (NIRS) for these purposes. The Figure 1 shows the items from searches regarding the application on intact fruit of the most important technologies. These data can be interpreted as evidence of NIRS's advantages. In fact, it has been suggested that among several techniques, NIRS has great potential for non-destructive determination of the internal attributes of fruit and its maturity [3].

Figure 1.

Quality can be defined from the intrinsic scope of the commodity, or regarding the consumer satisfaction [4-5]. The appearance of fruit is characterized by their colour, brightness, shape, size, and their possible defects. Their taste and flavor includes the sensory attributes acidity, astringency, bitterness, sweetness and other more or less specific. The texture integrates variables as firmness, hardness, floury, fibrousness, and juiciness. The nutritional composition of horticultural products, very important, includes its content of vitamins, minerals, bioactive compounds and carbohydrates. These components of fruit quality are measurable potentially by NIRS.

Factors affecting fruit and vegetables quality should be considered, highlighting the agronomic, environmental, genetic and physiological [6]. The physiology is particularly important in post-harvest because fruits and vegetables breathe, are alive and evolve. Therefore, their quality parameters are specific at every phase during shelf life. This make monitoring these parameters becomes especially important [7]. Physiological changes during postharvest are most pronounced in fruit, particularly in climacteric fruit, because the climacteric is a key trigger to major changes of quality. Thus, quality monitoring is even more important in these products. Harvest, conservation and storage methodologies can be scene of action for NIRS.

The quality parameters considered usually in quality standards are often insufficient when it comes to defining the consumer degree of satisfaction [8]. Hence, in certain cases it may be advisable to include sensory aspects in product commercial characterization [9]. These aspects are taken into account, for example, in breeding processes for developing new varieties [10]. Overall, plant breeding has sought to increase production or extend the duration of produce, which has impacted on some commodities in a reduction of the intensity and diversity of its sensory attributes [11-12]. Sometimes fruit sensory attributes are affected indirectly by intervening crop management factors, such as date of harvest [13]. NIRS technology perhaps can help to monitor these fruit characteristics.

Another very important issue regards with pesticide residues. Microbial toxins and possible toxic own have also to be controlled. Nutritional aspects which are the subject of a growing appreciation are the contents of some phytochemical [14]. These scopes can be subject of NIRS measurements.

Analysis of fruit and vegetable quality by NIRS

Karl Norris is regarded as the ‘father’ of the modern Near Infrared Spectroscopic analysis. His laboratory was engaged in the 60’s on developing a rapid method of measuring the moisture content of wheat flour. After several avatars, measurements of moisture, protein and oil on the flour, were achieved together. [15]. The deed was greater than expected, since a multi-parametric technique was reached. Their initial work was in the field of agricultural products, but soon the interest reached many other areas [16].

NIRS (750-2500 nm) uses the interaction between the matter and the near-infrared radiation of the electromagnetic spectrum to characterize some properties from a given material. The NIRS spectra are dominated by absorption bands associated with the functional groups CH, OH or NH. The sum of these vibrations originates combination bands or overtones which are approximately multiples of the fundamental frequencies [17]. This means NIRS spectra are much more complex than they appear.

The most current applications of NIRS spectroscopy correspond to the food sector. These includes from determination of protein, moisture, fat and fiber on grains or flours, or the quality characterization of products as diverse as coffee, honey, meat or fish, including authentication applications of geographical origin of food. NIRS facilitates also the determination of qualitative properties in substances diverse, from gasoline to pharmaceutical tablets [18]. A growing number of NIRS applications are being used in sectors as the pharmaceutical [19] or the environmental [20]. Also, its medical applications are developing. The blood hemoglobin quantification or applications in plastic and reconstructive surgery [18] or brain studies [21] can serve as example.

The development of new techniques for selecting the measurement wavelengths has been the driving force in the increasing diversity of NIRS instrumentation [22]. The wavelength selection is based mainly on fixed and variable filters, diffraction gratings, scanning monochromators, diode array, and interferometer technology. The diode-array systems provide high acquisition speed without moving parts, what enables them to be mounted on fruit grading lines [23]. The acousto-optic tunable filters (AOTF) and liquid crystal tunable filters (LCTF) allows also rapid wavelength switching and the sequential scanning [22].

The NIRS measurement mode most frequent for several parameters on intact fruit is reflectance, else the transmittance and interactance modes are useful. Predictive outcome slightly higher was reported using transmittance, regarding reflectance and interactance, for SSC and TA measurement in intact mandarins [24]. However, results good have been reported using reflectance mode with the same fruit [25-26], orange [27-28] and with wide variety of fruits [29]. The reflectance, moreover, is the easiest mode to obtain measurements, since contact with fruit is not required and light levels are relatively high [30]. In the transmission mode, measurements are expected to be more influenced by fruit size, the amount of light penetrating the fruit often very small, thus making it difficult to obtain accurate transmission measurements at grading line speeds [31].

Among several technical aspects to consider, may be noted that NIRS spectrum is sharply temperature dependent [32]. Therefore, procedures should be considered both in calibrations development and its use, to ensure the adequate temperature limits for the samples, environment and equipment. On working conditions most common, the temperature of the sample has a much greater influence than the ambience's or of spectrometer. because the spectrum is the result of physical and chemical properties of the sample. Therefore, one suitable procedure is ensuring, by adequate laboratory practices, that sample temperature is the same used for calibration development. Methodology has been reported to compensate temperature influence on the spectral data by application of a special calibration equation [33], and also other temperature compensation procedures [34].

Important also, if a non-destructive technique is based on using predictive models as the case of NIRS, it is an indirect technique. Models are correlations multiple between values from conventional analytical method and variables spectral. Thus, the methodology should incorporate validation protocols. The application of a multi-parametric technique as NIRS makes necessary to use as many models as parameters, each model having its own validation protocol.

Very important is using appropriate statistics to assess the prediction performance. The squared coefficient of calibration, R^2, depends strongly upon the variance from the samples set. Moreover calibration statistics reflect the model fitness, but no its performance. External validations statistic, hence, should always be considered. The residual predictive deviation (RPD) is the statistic most consensual [35], useful to compare values of different parameters. Where this information does not exist, model predictive ability is not sufficiently demonstrated.

The potential of NIRS spectroscopy as rapid, nondestructive and multi-parametric technique, makes most of its applications on post-harvest are made in the product intact [36]. Moreover, fruits including those from horticultural crops such as tomatoes, melons, watermelons, peppers and other, are the most frequent objective of NIRS analysis on postharvest, because of the changes characteristic of their evolution. Other horticultural commodities as tubers, particularly potatoes [37-38], roots [39-45], and at lesser extent bulbs [46] and mushrooms [47] have also been target for NIRS technology. Its use in leafy vegetables up to the present has had much less importance. The juices has also been target for NIRS analysis, it being reported successful for several parameters [48-49], and produced from several fruit, as oranges [50-51], grapes [52-53] or bayberry [54].

Judging by developments found in the bibliography up to the present, the use of NIRS in postharvest got its start from assessing fruit maturity by the properties of light transmission. [55]. First applications of NIRS technology by reflectance in postharvest were aimed also to assessing ripeness [56] and the detection of internal defects [57]. The possibility of using NIRS to indirectly determinate the fruit content of sugars, by reference to the soluble solids content, soon was explored [58] and also the determination of dry matter [46, 59]. Apples are the fruit in which NIRS further has been the subject of research, from its first applications in postharvest. The potato records the second position in the ranking in bibliographic databases. Several mandarin varieties, particularly Satsuma, were within the first fruits NIR analyzed [24-26, 31, 60-63]. Tomato is the following commodity in quantitative importance [64, among others]. Orange fruit has received rising attention in recent years [27-28, 50, 65].

The main chemical parameters of fruit quality are their soluble solids content (SSC) and total acidity (TA). Its relation is frequently used as maturity index, along with its colour. Another constituent frequently abundant in the fruit and interesting for health is the pectin. Its prediction by NIRS has been reported suitable in pear [66] and apple [67]. The analysis by NIRS of SSC of intact fruit is reported successful in a large quantity of fruits, as those included in Table 1.

Table 1

Total acidity (TA) prediction by NIRS has been considered difficult to achieve on intact fruit, due to its relatively low levels of organic acids [24-25]. Several authors have reported various levels of success in predicting TA of diverse fruit, shown in Table 1.

In fruit no-climateric, as citrus and grapes, sugars and acids are fairly stable before and after harvest. The ratio between both parameters, represented by SSC and TA, is the key to consumer acceptability and widely used as maturity criterion in these fruit. When the target of NIRS analysis is maturity index defined by the ratio SSC to TA, predict directly this parameter very probably will bring better results than do it separately for both components, as has been reported with oranges. [28]. This methodology could be, in these cases, a solution to difficulty of determining total acidity.

The NIRS spectra are the result from radiation and sample interactions, and reflect its physical and chemical properties. Fruit features such as firmness, juiciness, weight and colour, among others, are properties physical. The fruit softening is used often as criterion for selecting the most suitable harvest date in several commodities [143]. Several methods are used to destructive measurement of fruits firmness [143-145], or requiring their harvest [146-147]. Some can be used directly on the tree [148-149]. The possibility of nondestructive fruit firmness assessing by NIRS has been revised [149-150] and reported suitable for several fruit, included in Table 1.

The juiciness is a very important attribute [157]. Results successful of NIRS calibrations for citrus’s juiciness prediction have been reported in mandarin [25], and orange [28]. It has been reported useful for this purpose, combined with other techniques, in apple [158]. However, the usefulness of NIRS for predicting this parameter in fruit has been little investigated to date.

The possibility of estimating fruit weight by NIRS has rarely been reported. The exploration of this possibility is of great interest, since fruit weight could be added to other parameters such as CSS, TA or fruit firmness as different outputs from a single NIRS measure. In fact, some good outcomes have been found on nectarine [80], orange [28], and olives [159].

It is reasonable to think fruit colour can be correlated with the visible spectrum to a greater extent than with its near-infrared spectrum. However, it has been reported the possibility of assessing tomato colour successfully by NIRS using 600-1100 nm wavelengths [153]. Good predictions of the apple's colour by Visible and NIRS spectroscopy (Vis/NIRS) has been reported [101], as well the chlorophyll content in bananas [160].

Another area for NIRS is assessment of the internal fruit defects. Nondestructive detection of section drying in tangerines [161], brown heart of pears [162-163], internal defects [164-165] and NIRS transmission on-line for brown heart detection on apples [166], has been reported. Also, predicting storage disorders of kiwifruit [96, 167-168], detecting water core in apples [169], or internal disorders of intact mangosteen [170]. As well, superficial bruises on apple have been measured by NIRS [171]. The presence of insect larvae in fruit, which in some cases is of great importance, can be NIRS detected, as reported by several authors [172-175].

The fruit sensory quality characterization by NIRS or Vis/NIRS is an area of great interest [176]. There are evidences that some fruit's sensory attributes could be successfully predicted by NIRS. This is the case with sweetness, because there are good correlations between SSC and consumer acceptance of several produce as tomato [176] citrus fruit [177-179], plum [180], peach and nectarine [181], apple [182], kiwifruit [183], melon [184] or cherry [185], among others. Also other fruit parameters as firmness are related to consumer acceptance [82]. Sensory attributes of apples [157], mango [113] and tomato [152] has been reported as Vis/NIRS predictable. However, the development of NIRS predictive models using fruit's sensory attributes as reference, assessed by tasting panels, has been little investigated to date.

At the same time, interest increasing are receiving NIRS applications for determining minor components, phytochemicals, whether in samples prepared for analysis or intact [14], because of their importance to health. The content of nutraceuticals on blueberries [132], carotenes of banana [186], carrot [187] and potato [188], the lycopene tomato content [189], glucosinolates from cabbage [190] or vitamin C in several fruits [191], including oranges [192] and strawberry [193] has been subject of NIRS measuring. Nasunin, a potent antioxidant of eggplant's fruit skin, also has been NIRS estimated [194].

The reliability of pesticide determination using NIRS is being explored [195-198]. However, the technique's accuracy on intact fruit has not yet been sufficiently proven.

Systems NIRS for fruit sorting

Growing consumer awareness on food quality has led to rising valuation of fruit's sorting systems based on internal attributes. The commercial application of NIRS spectroscopy in fruit grading lines at pack-houses, for sorting fruits by its SSC, was initiated in Japan in the mid 1990s. Grading lines equipped with NIRS sensors potentially applicable to fruit are commercially available from several manufacturer, the most notable are included in Table 2. However, scientific information about the accuracy of these systems is scarce [23]. The issue has been subject of some reviews

[8, 199-201], although the research on targets specific is limited. Brown heart of apples has been also subject of NIRS on-line detection [166]. The effect of fruit moving speed on predicting SSC has been reported in pears [202].

Table 2

NIRS's portable instruments and possibility of use in field

One of the advantages of NIRS spectrometry can be the portability, if measurement must be *in situ*. A few models of portable NIRS spectrometers of several brands are available, but those specifically designed to fruit monitoring are few. Portable instruments NIRS or Vis/NIRS has been reported useful for non-destructive assessment of quality of several fruit, as those included in Table 3. NIRS's portable device use in a logistic platform [221] and evaluating fruit maturation in the orchard [222-223] was also reported. The development of a portable NIRS instrument for fruit sugar measuring has also been described [203].

Table 3

Summary

So far, have been devoted significant efforts to research on different aspects of NIRS technology applications in quality measures in the post-harvest fruits and vegetables. The ability of the technique to characterize quality attributes of a great variety of produce is now sufficiently contrasted. The use of this technology in practical applications, however, in many cases is far below its potential development. Ensure the sufficient model robustness is very important for obtaining the accuracy needed. The adoption of working conditions and procedures adequate for the use of predictive models and its validation may be trigger key for the extension of its implementation in the different stages of the chain. This could facilitate improved monitoring of the quality of fruits and vegetables.

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