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Chapter

Application of Visible to Near-Infrared Spectroscopy for Non-Destructive Assessment of Quality Parameters of Fruit

Khayelihle Ncama, Lembe S. Magwaza, Asanda Mdithsha and Samson Z. Tesfay

Abstract

The accuracy and robustness of prediction models are very important to the successful commercial application of visible to near-infrared spectroscopy (Vis-NIRS) on fruit. The difference in physiological characteristics of fruit is very wide, which necessitates variance in the type of spectrometers applied to collect spectral data, pre-processing of the collected data and chemometric techniques used to develop robust models. Relevant practices of data collection, processing and the development of models are a challenge because of the required knowledge of fruit physiology in addition to the Vis-NIRS expertise of a researcher. This chapter deals with the application of Vis-NIRS on fruit by discussing commonly used spectrometers, data chemometric treatment and common models developed for assessing quality of specific types of fruit. The chapter intends to create an overview of commonly used techniques for guiding general users of these techniques. Current status, gaps and future perspectives of the application of Vis-NIRS on fruit are also discussed for challenging researchers who are experts in this research field.

Keywords: near-infrared spectroscopy (NIRS), chemometrics, multivariate data, fruit quality

1. Introduction

The quality of fruits is produced in the orchard or garden and only maintained during postharvest storage [1]. This necessitates accurate determination of the optimal harvest time and a deeper understanding of physiological changes occurring in fresh fruit during storage. The main goal of postharvest management is to delay senescence by reducing the ripening processes and other physiological processes such as respiration [2]. The quality of fruit at commercial consignments is commonly assessed using techniques such as reflectometer-based determination of total soluble solutes (TSS), fruit mass or firmness tests [3]. The fruits selected as samples for assessment of parameters such as juice TSS are wasted because after they are destructed they cannot be returned to the batch. Therefore, the quantity sent by a farmer does not reach the destined market in its original quantity. Moreover, the
fruits taken as samples may not properly represent the actual status of the batch. The challenge of sample size is significant in huge farms that require a large number of representative samples. It is also known that fruits from the same batch, same tree and the same branch of a tree are likely to differ in quantities of their quality parameters. It is therefore necessary to find non-destructive alternative techniques that can be used to analyse the entire batch without losing any samples.

Techniques such as mass and firmness determinations do not destruct sample fruit. However, most fruits are very perishable and develop bruises if they experience successive external impact [4, 5]. Moreover, the physical parameters such as mass and firmness cannot be associated to organoleptic qualities with accuracy. A big fruit does not warrant a better taste than a small fruit. Therefore, the elevated purchase price of big fruit based on mass is not a justified technique for customers. The firmness tests can be used to determine the level of ripeness and associated with the edibility of climacteric fruit such as avocado and mango. However, the firmness cannot be directly associated to flavour because flavour is determined by the levels of certain biochemical compounds that should be analysed from the consumed fruit part. It is for these reasons that application of spectrometers is necessary since they can analyse quantities of biochemical compounds without excessive contact with a fruit. Spectrometers can be a very useful tool for growers who want to non-destructively determine fruit parameters that are used to track optimal time of harvesting. Application of hand-held spectrometers on hanging fruit can eliminate the estimation of harvest time using few samples that sometimes do not fully represent the entire orchard [6, 7]. Moreover, they preserve the sample fruit that would be wasted if destructive methods were used. In postharvest storage, visible and near-infrared spectroscopy (Vis-NIRS) can be applied in various forms where fruit would be passed under a radiation chamber and be analysed for physical, chemical and organoleptic properties whilst rolling on sorting belts [8]. The Vis-NIRS holds many advantages over destructive or contact techniques. Analyses of every fruit in a batch, mechanised precision that lasts longer than human effort and reduction of fruit waste as a result of specified management are among major benefits that can be obtained from Vis-NIRS applications.

2. Spectrometers commonly applied in acquisition of spectra from fruit

The trade names may differ from one supplier to the other. However, the type of spectrometers commonly used can be properly categorised based on their operation mode. Vis-NIRS operates in three common modes: the reflectance, transmittance and interactance (diffuse reflectance) modes [9]. Reflectance is the most common mode of acquiring spectra from fresh fruit. Although it can be associated with the type of spectrometers commonly available, it is also a less restricted mode compared to others. Other modes such as transmittance would require that the radiation passes through the sample fruit which is sometimes inefficient because radiation may not reach the other side of a fruit due to disturbances such as a stone, seeds or hollow spaces inside the fruit. Hereon, the common spectrometers applied on specific fruit types will be reviewed and associated with the botanic characteristics of the fruit.

2.1 Stone (drupe) fruits

Stone fruit, also called drupe fruit, is an indehiscent fruit characterised by a thin sheet as exocarp, fleshy mesocarps and a hard endocarp. The hard endocarp usually contains a single seed and is referred to as a stone because of its high firmness [10]. Examples of drupe fruit are peaches, nectarines, plums, lychees, mangoes, avocados
and cherries. Application of Vis-NIRS on stone fruit for assessing organoleptic parameters requires awareness about the stone that can interfere with radiation. As a result, most researchers would avoid using spectrometers that use transmittance mode as most radiation is likely to be deflected or absorbed by the stone inside the fruit. Spectrometers working on reflectance and interactance modes are the most relevant methods if the analysis is not associated with a stone [11]. The choice of a spectrometer can depend on the assessed fruit quality. Transmittance mode would be appropriate if the objective is to analyse the size or hardness of the stone.

The appropriateness of reflectance mode is achieved when the spectra are collected for assessing parameters in the mesocarp. Assuming that the number of streams illuminated by the spectrometer (n) is 4, Figure 1 illustrates the assumption of radiation paths the radiation can pass through if the hypothetical radiation is applied in three different modes. One, three or one of the four arrays reaches the sensor if a transmittance, reflectance or interactance mode is used, respectively.

2.2 Berry or aggregate fruits

Botanically, a berry or aggregate fruit is made up of more than one seed containing fruitlets produced from a single ovary [12]. Common examples include citrus, banana, pineapples, cucumber, tomatoes and grapes. The term berry fruit is commonly used to refer to small pulpy fruit with thin coat-like exocarp tissues covering the fleshy edible mesocarp. Examples of fleshy berries are strawberries, raspberries, mulberries, blackberries, blueberries, redburrants and blackcurrants. The main factor of consideration in application of Vis-NIRS on aggregate fruit is that the fruit is formed as a combination of smaller fruit which can vary in biochemical composition [13]. The uneven ripeness of berry fruit is significant on vine fruit such as grapes, which may necessitate the use of spectrometers that consider each fruit in the bunch as a single fruit. Any mode of spectrometer can be used on aggregate fruit. This is due to their fleshy internal structure and few or tiny seeds interfering with the radiation passing through the fruit. However, the important consideration is that the size of the radiation source is fully covered and the fruit size can enable passage of radiation from the source to the detector if the transmittance mode is used. Lammertyn et al. [14] investigated the distance that a light beam can penetrate into the fruit. The authors found that there was a wavelength-dependent effect that showed that the regions in 700–900 and 900–1900 nm reach around 4 and 2–3 mm,
respectively, which showed that a more intensified illumination was required to obtain a penetration of greater depth if the transmittance spectrum was required.

2.3 Pome fruit

Pome fruit are characterised by a thin exocarp, edible mesocarp and a soft endocarp. Their seeds are in the part called an endocarp or a pit which is relatively harder than the edible mesocarp but softer than the endocarp of stone fruit [15, 16]. Common examples of pome fruit are apples, pears, cotoneaster, crataegus (hawthorn and mayhaw), loquat, medlar, pyracantha, toyon, quince, rowan and whitebeam fruit. Application of Vis-NIRS on pome fruit can be in any form depending on the objective of the assessment. The hardness of endocarp can be used as a measure of maturity of pome fruit [17, 18]. If maturity is assessed, the endocarp is not considered as interference in the transmittance mode which requires radiation to pass through the fruit. However, the endocarp is likely to differ from one fruit to another irrespective of common characteristics such as maturity stage or size. Two fruits of the same maturity stage and the same size may have a different number of seeds. Using transmittance mode can reduce the assessment accuracy when the quality parameters of interest are in the mesocarp.

3. Chemometric treatment of spectral data obtained from fruit

Most spectrometers acquire a full visible to near infrared radiation spectra ranging from 450 to 2500 nm. However, theory suggests that organic components with concentrations higher than 0.1% in fruit have their particular range on the visible or near-infrared wavelengths that result to their best reflection [9]. As such, most researchers always select specific ranges where the analysed compound is likely to respond. However, some fruit quality parameters may be best reflected by the entire spectra [19]. The use of the full spectral range is somehow superior to using specific ranges since it provides a wide source of reference points along the spectrum. The general steps of chemometric analysis applied to spectral data collected from fruit are (i) selecting the wavelength range, (ii) pre-processing raw data to derivatives, (iii) calibrating prediction models and (iv) validating the performance of the developed models on independent external test set. Based on the objective of the study, a researcher can either develop quantitative or qualitative models.

The necessary results that authors show are after validation. The most important model parameters of reference are correlation coefficient ($R^2$) and the root mean squared error of prediction (RMSEP). A good model is selected based on high $R^2$ value and low RMSEP value which are the main parameters of consideration, although there are other parameters such as the ratio of performance deviation (RPD) and bias. RPD is widely used as a reference parameter of the performance of prediction models. However, there is lack of information on how was the system developed, and the relationship between the $R^2$ values and RPD values is in exponential form, whilst it should be linear if both values can be used as references to judge models’ accuracy [20]. Therefore, the most necessary parameter is the $R^2$ value because of its simplicity and a traceable statistical development of its relevance. The $R^2$ values range from 0 (poor model) to 1 (best model), and anything in between can be related to its proximity to the mentioned extremes. The RPD values cannot be simplified to that level of stating the maximum and minimum values. Several authors refer to Chang et al. [21] who invented the three quality categories of model reliability: excellent models (RPD > 2), fair models (1.4 < RPD < 2) and non-reliable models (RPD < 1.4). However, those authors did not give any statistical basis of the mentioned thresholds.
3.1 Quantitative models

Quantitative Vis-NIRS models are those that estimate the exact quantity of a physical or biochemical compound. They hold a higher advantage in the assessment of quality parameters that cannot be categorised into distinct groups but characterised by a continuous range. Partial least square (PLS) regression (PLSR) is arguably the most used quantitative model by researchers. In PLS models, an orthogonal basis of latent variables is constructed one by one in such a way that they are oriented along directions of maximal covariance between the spectral matrix and the response value [22]. The technique was introduced by Herman Wold in 1975 as an improved modification to overcome collinearity of multiple linear regressions [23]. A unique feature of basic PLS regression is its simplicity. The basic PLS method consists of a series of simple least square optimisation called nonlinear iterative partial least squares NIPALS; [24]. The PLS technique also accounts for noisy and redundant spectral variables and can analyse more than one chemical variables at once.

The majority of recent research reports are based on its different manipulations. As a result, models such as interval partial least squares (iPLS), interval successive projection algorithm (iSPA-PLS), moving window partial least squares (MWPLS) and other PLS modifications were introduced or reinvented in the last decade [25–27]. The PLS modelling was developed by Wold in 1981 [28], and majority of researchers have referred to it as a pivot point of regression models. The following section looks at the common quantitative models for specific types of fruit. Hereon, examples of studies that developed quantitative models for stone fruit and nuts (Table 1), berries and aggregate fruit (Table 2) and pome fruit (Table 3) are reviewed.

<table>
<thead>
<tr>
<th>Fruit</th>
<th>Assessed quality parameter(s)</th>
<th>NIR mode used</th>
<th>Spectral range</th>
<th>Vis-NIRS models developed</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almond</td>
<td>Amygdalin content</td>
<td>Diffuse reflectance mode</td>
<td>888–1795 nm</td>
<td>PLS</td>
<td>[29]</td>
</tr>
<tr>
<td>Date</td>
<td>TSS, moisture content and colour</td>
<td>Reflectance</td>
<td>285–1200 nm</td>
<td>PCR</td>
<td>[30]</td>
</tr>
<tr>
<td>Jaboticaba</td>
<td>Total anthocyanin content</td>
<td>Reflectance</td>
<td>714–2500 nm</td>
<td>iSPA-PLS, PLS and GA-PLS</td>
<td>[25]</td>
</tr>
<tr>
<td>Mango</td>
<td>TSS, firmness, TA and rind pitting index</td>
<td>Reflectance</td>
<td>700–1100 nm</td>
<td>PLS</td>
<td>[31]</td>
</tr>
<tr>
<td>Olives</td>
<td>Fat content, moisture and free acidity</td>
<td>Reflectance</td>
<td>380–1690 nm</td>
<td>PLS and LS-SVM</td>
<td>[32]</td>
</tr>
<tr>
<td>Peach</td>
<td>Days before decay</td>
<td>Reflectance</td>
<td>900–2500 nm</td>
<td>PLS, LS-SVM and MFRG</td>
<td>[33]</td>
</tr>
<tr>
<td>Plums</td>
<td>SSC, TA, juice pH, TSS/TA and firmness</td>
<td>Interactance</td>
<td>500–1010 nm</td>
<td>PLS</td>
<td>[34]</td>
</tr>
</tbody>
</table>

LS-SVM, least squares support vector machine; MFRG, multiple fitting regression based on Gaussian fitting function; PLS, partial least squares regression; PCA-LDA, principal component analysis-linear discriminant analysis; SPA-LDA, successive projection algorithm-linear discriminant analysis; GA-LDA, genetic algorithm-linear discriminant analysis; PCR, principal component regression.

Table 1. Application of Vis-NIRS for assessing quality parameters of stone fruits or nuts.
In the realm of Infrared Spectroscopy—Principles, Advances, and Applications, we delve into the assessment of fruit quality through various modes and spectral ranges.

**Fruit Assessed | quality parameters | NIR mode used | Spectral range | Vis-NIRS models developed | Reference**
--- | --- | --- | --- | --- | ---
Blackberries, wild blueberries, raspberries, redcurrants and strawberries | Total phenolic compounds and antioxidant activity | Reflectance | 904–1699 nm | PLS | [35]

**Citrus colocynthis** | Total polyphenol content | Absorbance | 700–2500 nm | PLS | [36]

Mandarins and oranges | Mass, colour, fruit diameter, firmness, pericarp thickness and juice mass | Reflectance | 1600–2400 nm | MWPLS | [26]

Mulberry | SSC | Reflectance | 400–2500 nm | PLS | [19]

Pineapple | Nitrate level | Interactance | 600–1200 nm | PLS | [37]

Strawberry | TSS and pH | Reflectance | 10,494–3673 cm⁻¹ | SIMPLS | [38]

Strawberry | TSS | Interactance | 4000–10,000 cm⁻¹ | iPLS and MWPLS | [27]

Tomato | Firmness | Reflectance | 500–1700 nm | PLS | [34]

Watermelon | Lycopene, β-carotene and TSS | Reflectance | 900–1700 nm | PLS | [8]

PLS, partial least squares regression; SIMPLS, soft independent modelling partial least squares regression; iPLS, interval partial least squares; MWPLS, moving window partial least squares.

**Table 2.** Application of Vis-NIRS for assessing quality of berry or aggregate fruit.

---

**Fruit** | **Assessed quality parameters** | **NIR mode used** | **Spectral range** | **Vis-NIRS models developed** | **Reference**
--- | --- | --- | --- | --- | ---
Apple | SSC | Interactance | 500–1100 nm | PLS | [39]

Loquat | Moisture content | Reflectance | 750–2500 nm | PLS | [40]

Pears | TSS | Reflectance | 710–930 nm | PLS | [41]

Pears | SSC | Reflectance | 930–2548 nm | PLS | [42]

Pears | SSC and firmness | Absorbance | 500–1010 nm | PLS and MLR | [43]

Persimmon | Astringency and tannin contents | Interactance and transmittance | 600–1100 nm | PLS | [44]

Wax jambu | Total phenolic compound content | Interactance | 1000–2400 nm | PLS | [45]

PLS, partial least square regression; MLR, multiple linear regression.

**Table 3.** Application of Vis-NIRS for assessing quality of pome fruit.
Table 4. Application of Vis-NIRS for classification of stone fruit and nuts.

<table>
<thead>
<tr>
<th>Fruit Classification parameter</th>
<th>NIR mode used</th>
<th>Spectral range</th>
<th>Vis-NIRS models developed</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almond Amygdalin content</td>
<td>Interactance</td>
<td>888–1795 nm</td>
<td>LDA, QDA and PLS-DA</td>
<td>[28]</td>
</tr>
<tr>
<td>Hazelnuts Regions and cultivars</td>
<td>Transmittance</td>
<td>650–4000 cm⁻¹</td>
<td>PCA, LDA and PLS-DA</td>
<td>[47]</td>
</tr>
<tr>
<td>Almond nuts Concealed damage</td>
<td>Reflectance</td>
<td>1125–2153 nm</td>
<td>PLS-DA</td>
<td>[48]</td>
</tr>
<tr>
<td>Jaboticaba Cultivars</td>
<td>Reflectance</td>
<td>1000–2500 nm</td>
<td>PCA-LDA, SPA-LDA and GA-LDA</td>
<td>[49]</td>
</tr>
<tr>
<td>Macadamia nuts Variety</td>
<td>Reflectance</td>
<td>11,544–3952 cm⁻¹</td>
<td>PCA-LDA and GA-LDA</td>
<td>[50]</td>
</tr>
<tr>
<td>Peach Cultivars</td>
<td>Reflectance</td>
<td>800–2600 nm</td>
<td>PCA, UVE-PLS and SPA</td>
<td>[39]</td>
</tr>
<tr>
<td>Pine nuts Geographic origin</td>
<td>Reflectance</td>
<td>400–2500 nm</td>
<td>PLS-DA</td>
<td>[51]</td>
</tr>
</tbody>
</table>

Table 5. Applications of Vis-NIRS for classification of berry or aggregate fruit.

<table>
<thead>
<tr>
<th>Fruit Classification parameter</th>
<th>NIR mode used</th>
<th>Spectral range</th>
<th>Vis-NIRS models developed</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blackberries, wild blueberries, raspberries, redcurrants and strawberries</td>
<td>Total phenolic compounds and antioxidant activity</td>
<td>Reflectance</td>
<td>904–1699 nm</td>
<td>PCA</td>
</tr>
<tr>
<td>Citrus Firmness</td>
<td>Reflectance</td>
<td>400–1750 cm⁻¹</td>
<td>Raman signal</td>
<td>[52]</td>
</tr>
<tr>
<td>Mulberry leaf Pesticide residue</td>
<td>Reflectance</td>
<td>390–1050 nm</td>
<td>PLS-DA</td>
<td>[53]</td>
</tr>
<tr>
<td>Nectarine Variety</td>
<td>Reflectance</td>
<td>360–1795 nm</td>
<td>LDA and PLS-DA</td>
<td>[28]</td>
</tr>
<tr>
<td>Strawberry Organic and conventionally grown fruit</td>
<td>Reflectance</td>
<td>12,500–3600 cm⁻¹</td>
<td>PLS-DA</td>
<td>[38]</td>
</tr>
<tr>
<td>Tomato fruit Ripeness</td>
<td>Interactance</td>
<td>400–1000 nm</td>
<td>PLS-DA</td>
<td>[54]</td>
</tr>
<tr>
<td>Tomato fruit Lycopene content</td>
<td>Reflectance</td>
<td>275–1150 nm</td>
<td>PLS-DA</td>
<td>[55]</td>
</tr>
</tbody>
</table>

LDA, linear discriminant analysis; QDA, quadratic discriminant analysis; PCA, principal component analysis; PLS-DA, partial least squares regression discriminant analysis; UVE-PLS, uninformative variable elimination based on partial least squares; PCA, principal component analysis; SPA, successive projection algorithm; PCA-LDA, principal component analysis-linear discriminant analysis; GA-LDA, genetic algorithm-linear discriminant analysis.
### 3.2 Classification models

Most fruit growers classify their crop into different quality classes in order to state their selling price and target different markets. Fruit destined for a local market may not be at the same level of quality as fruit destined for exports to international markets. Fruit can be sorted based on their maturity level, colour, origin, size and other characteristics of interest to consumers. This necessitates an effective way of classifying many fruits at short period of time. The Vis-NIRS technique has been shown to have an ability to assess a minimum of three fruits per second [46], which is way faster than the potential of a human panel normally used on commercial scales. The following tables exemplify the studies that demonstrated the ability of Vis-NIRS to classify stone fruit and nuts (Table 4), berry and aggregate fruit (Table 5) and pome fruit (Table 6). Notably, researchers have an extended freedom of choice in selecting classification models compared with quantification models. However, partial least square discriminant analysis (PLS-DA) and linear discriminant analysis (LDA) are the commonly used models for fruit. Discriminant analyses use a principal component analysis (PCA) for extracting, compressing and screening multivariate data such as spectra. The PCA technique employs a mathematical procedure that transforms a set of response variables into a set of non-correlated variables called principal components. PCA produces linear combinations of variables that are useful descriptors or even predictors of some particular structure in the data matrix [64]. Although typically used for spectral data, different classification models can also be used for mapping data matrix of any type.

<table>
<thead>
<tr>
<th>Fruit</th>
<th>Classification parameter</th>
<th>NIR mode used</th>
<th>Spectral range</th>
<th>Vis-NIRS models developed</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apples</td>
<td>Cultivars</td>
<td>Reflectance</td>
<td>4000–10,000 cm⁻¹</td>
<td>Fuzzy linear discriminant analysis and fuzzy c-means clustering</td>
<td>[56]</td>
</tr>
<tr>
<td>Apples</td>
<td>Bitter pit</td>
<td>Reflectance</td>
<td>971.2–1142.8 nm</td>
<td>QDA and SVM</td>
<td>[57]</td>
</tr>
<tr>
<td>Apples</td>
<td>Bitter pit</td>
<td>Reflectance</td>
<td>935–2500 nm</td>
<td>Spectral pattern recognition</td>
<td>[58]</td>
</tr>
<tr>
<td>Apples</td>
<td>Cultivars</td>
<td>Reflectance</td>
<td>1000–2500 nm</td>
<td>PCA</td>
<td>[59]</td>
</tr>
<tr>
<td>Apples</td>
<td>Separating organic and inorganic fruit</td>
<td>Reflectance</td>
<td>900–1700 nm</td>
<td>Spectral pattern recognition and PLS-DA</td>
<td>[60]</td>
</tr>
<tr>
<td>Apples</td>
<td>Internal browning</td>
<td>Reflectance</td>
<td>740–1040 nm</td>
<td>Spectral pattern recognition</td>
<td>[61]</td>
</tr>
<tr>
<td>Chinese quince fruit</td>
<td>Varieties</td>
<td>Reflectance</td>
<td>1000–2500 nm</td>
<td>LDA, QDA and SVM</td>
<td>[62]</td>
</tr>
<tr>
<td>Persimmon fruit</td>
<td>Fruit origin</td>
<td>Reflectance</td>
<td>740–2700 nm</td>
<td>PCA and LS-SVM</td>
<td>[63]</td>
</tr>
</tbody>
</table>

LDA, linear discriminant analysis; QDA, quadratic discriminant analysis; PCA, principal component analysis; PLS-DA, partial least squares regression discriminant analysis; SVM, support vector machine; PCA, principal component analysis.

Table 6. Application of Vis-NIRS for classification of pome fruit.
4. Current status of spectroscopy application on fruits

4.1 Vis-NIRS application on fresh fruit

There are a great number of studies demonstrating the capability of Vis-NIRS to accurately assess biochemical and physical quality parameters of fruit. The commonly assessed compounds of fresh fruit include sugar contents, acidity, juice pH, pectin, firmness, etc. because of their direct link with being referred to as sorting categories [9]. Secondary factors of quality such as bruising, scars and other disorders are not commonly assessed. However, some studies have assessed factors indirectly associated with fruit quality such as postharvest disorders. The ability of Vis-NIRS to assess invisible internal disorders such as brown heart disorder of pears has been demonstrated [65]. Magwaza et al. [66] demonstrated the ability of Vis-NIRS to detect rind breakdown disorder of mandarins. The detection of presymptomatic attributes leading to disorders has also been demonstrated successfully on fresh fruit. Ncama et al. [67] demonstrated the ability of Vis-NIRS to detect susceptibility of fresh grapefruit to rind pitting disorder occurring in postharvest storage. The extent of Vis-NIRS application has been reported from the stable laboratory-based instruments, portal instruments and in sorting lines. The most fascinating studies were those that demonstrated the ability of Vis-NIRS to assess the quality of fruit in motion on sorting lines. Salguero-Chaparro and Peña-Rodríguez [32] successfully quantified the contents of fats, free acidity and moisture of intact olives using a system mounted on the conveyer belt. Such studies were a clear demonstration of the period at which commercial fruit growers should adopt the Vis-NIRS technique for sorting their fruit.

4.2 The application of Vis-NIRS on secondary products from fruits

Studies demonstrating the ability of Vis-NIRS on assessing quality of slices of fresh fruit are common. The importance of monitoring their quality can be associated to their altered respiration rate which may result to degradation of their quality at an elevated rate. Fruits have hard sheet-like peels that regulate their respiration and protect the flesh from carbon dioxide that leads to development of the browning pigments. It is for this reason that careful quality management is crucial after removing the exocarp of fruit.

Dried fruits have little biological activities occurring during their storage. As such, they have extended life span compared to fresh fruit. Their low biological activities only necessitate the determination of parameters associated to edibility such as taste and flavour only once immediately after the drying process. When fruits are dried, their taste parameters are nearly fixed. After the drying stage, the necessary factors to analyse are the protective substances such as biochemical compounds related with antifungal or antibacterial activities if their quality is also threatened by infections. On the other hand, juices and wines are judged by holding true to the manufacturer's flavour. This therefore calls for each and every bottle to hold similar characteristics to keep a trusting trade with customers. It is not the flavour-related parameters that require rapid assessment using Vis-NIRS but secondary metabolites associated to flavour such as phenolic compounds, vitamins, chloride, sulphate and mineral contents [68, 69]. The maturity stage (alcohol strength) of wines during fermentation can increase the accuracy of management. Rapid determination of titratable acidity of apple wine using Vis-NIRS during the fermentation process was demonstrated by Peng et al. [70].
Wine ageing in wooden barrels is aligned with improved final sensory profile and, therefore, price of purchase. It is for this reason that the process used during wine ageing needs to be traceable for insurance of trustworthy trading standards. Basalekou et al. [71] demonstrated the ability of Vis-NIRS to discriminate different wines based on variety, type of barrel and ageing time. Magdas et al. [72] demonstrated rapid discrimination of wines based on variety, vintage and geographic origin. The shelf life of wines and juices may also be predicted inversely by determination of fermentation and adulteration compounds. The common spectra acquisition mode used on liquid fruit product is the transmission mode. This is due to the uniformity of the liquid texture which does not deflect radiation throughout the sample. The light that is not absorbed by the liquid is then reported to a spectrometer as an absorbance spectrum. Fourier transform Raman spectroscopy method is the common type of spectra collected [73, 74]. However, Teixeira dos Santos et al. [69] revealed a better suitability of mid-infrared spectroscopy (87.7% of correct predictions) over near-infrared (60.4%) and Raman spectroscopy (60.8%) on classifying wines based on geographic origin.

5. Future perspectives

There are a lot of studies that demonstrated the ability of assessing quality of fruit by application of Vis-NIRS. The application of Vis-NIRS has been tested and approved on many varieties of fruit from different geographic conditions. Different data collection, pre-processing and chemometric analysis methods and different kinds of prediction models have been developed and demonstrated to accurately assess fruit quality. The next research step in this field is very hard to point out. Arguably, it is the right time to consider Vis-NIRS as an ordinary method of assessing quality parameters of fruit. Studies with an objective of demonstrating the application of Vis-NIRS with different modes, on different fruit or fruit cultivars, or using different chemometric methods and selecting the best method are no longer contributing any novelty of interest in research. Such experiments are most relevant to technicians who want to calibrate spectrometers for use in commercial lines but not as research investigations.

Significant recent research reports on demonstrating new application methods and new chemometric techniques or developing new types of models. To our knowledge, no report has defied the accuracy of PLS models. The reports then become unnecessary from the application point of view. As long as the ordinary PLS model or its modified forms are able to obtain 97% prediction accuracy on analysing TSS [75, 76], they are better than using the destructive reflectometer technique. As long as PLS models can obtain 90% accuracy on analysing total phenolic compounds [77, 78], they are better than the use of procedures based on protocols involving the use of chemicals and sophisticated laboratory equipment. Illustrating ways of increasing the accuracy of PLS models is of course important, but it does not contribute any novelty in the research. Vis-NIRS has been demonstrated in online systems [32], which should have been a signal that it is no longer new and can be a commonly used technique. The only novelty of intrigue to technicians would be developing models that hold 100% accuracy, which is also not astonishing because Vis-NIRS models are assessed based on predicting reference values of a parameter that is assessed by destructive techniques. Destructive techniques may have had errors and inaccuracies that arose from a non-calibrated human potency. Vis-NIRS can accurately predict incorrect reference data and create a precise model with incorrect calibration.
6. Conclusion

The research world has greatly demonstrated the potential of Vis-NIRS application for assessing quality of fruit. But the technique is still not common on commercial lines. The Vis-NIRS scarcity on commercial lines could be associated to the expensive prices of the spectrometers compared to weighing scales. As such, most supermarkets may choose to use the mass of fruit to determine the purchase price although not accurate since a big fruit does not give a warrant of a satisfying flavour. The fresh horticultural produce industry is one of the few food industries that do not indicate the nutritional characteristics of their product. Most processed food stuff has a table of contents of carbohydrates, fats, vitamins, etc. indicated on their containers. Customers nowadays are willing to pay extra prices for high nutritious fruit [9]. The nutritional information of fruit could be easily indicated if the Vis-NIRS technique is adapted in the market. Therefore, trustworthy trade relationship could be easily achieved since the biochemical components of fruit could be associated with the purchasing price. Buying the instrument is a once-off expense that will improve the industry for as long as there is no other superior technology invented. The next step in research should focus on gathering information or reasons that result to distributors and end market sellers not willing to adapt using Vis-NIRS. Teaching the public about Vis-NIRS is necessary because most people are not scientists and may not understand the safety of applying radiation on their food. It should be remembered that some people believe that biotechnology used to produce genetically modified organisms is a source of toxic food escalating diseases such as cancer [79].

Conflict of interest

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