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Article

Sensory Evaluation and Spectra Evolution of Two Kiwifruit Cultivars during Cold Storage

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Abstract: Kiwifruit consumption has increased due to its rich nutritional properties. Although 'Hayward' continues to be the main cultivar, others, such as yellow fleshed 'Jintao', are of increasing interest. The objective of this research was to evaluate the acceptability and storage performance of these two cultivars. Sensory evaluation of green 'Hayward' and yellow 'Jintao' kiwifruit were performed along cold storage for three seasons/years to follow the organoleptic characteristics through ripening, as well as the acquisition of their spectra by Vis-NIR. For 'Jintao' were performed two sensory evaluations per year at 2.5- and 4.5-months' storage and for 'Hayward' at 2.5-, 4.5- and 5.5-months' storage. The nonparametric Mann–Whitney test and Kruskal–Wallis ANOVA were performed to test the significant differences between the mean ranks among the storage time. A non-metric multidimensional scaling plot method using the ALSCAL algorithm in a seven-point Likert scale was applied to determine the relationships in the data, and a new approach using the receiver operating characteristic (ROC) analysis was tested. The last revealed that, for both cultivars, sweetness, acidity and texture were the variables with better scores for General flavor. Aroma was also important on 'Jintao'. A strong correlation between soluble solids content (SSC) and reflectance was found for both cultivars, with the 635–780 nm range being the most important. Regarding firmness, a good correlation with reflectance spectra was observed, particularly in 'Hayward' kiwifruit. Based on these results, Vis-NIR can be an objective alternative to explore for determination of the optimum eating-ripe stage.

Keywords: kiwifruit; Vis-NIR spectroscopy; ripening; sensory evaluation; ROC analysis

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1. Introduction

Kiwifruit is an economically important crop due to its taste and high nutritional properties [1,2]. The green fleshed *Actinidia deliciosa* cv. Hayward is the most commercialized cultivar on the international market, because of its size, taste and long storage life [3,4], maintaining good quality in terms of texture, flavour and freedom from disorders [5]. In fact, approximately 90% of the kiwifruit commercialized is 'Hayward' [6]. However, in recent years, yellow-fleshed *A. chinensis* var. *chinensis* cultivars 'Hort16A' 'Jintao', 'Zesy002′, 'Zesy003′, 'Soreli' and 'Dori' are becoming more popular [7]. The 'Jintao' cultivar selected at the Wuhan Institute of Botany (WIB), China, was introduced into Europe for evaluation in 1998, and as increased the growing area and interest, since then [8].

The aroma of kiwifruit is the result of a subtle mixture of volatile compounds [9]. 'Hayward' has a more acidic taste, described as grassy and sulphurous with a melon and sweet candy flavour at eating-ripe [10], while the yellow-fleshed kiwifruit has an intense tropical flavour [11], sweeter and with a higher commercial value than the green fleshed ones [3]. As climacteric fruit, during storage, mature kiwifruit ripens to an acceptable eating state by several changes including conversion of starch to soluble sugars and the softening of the flesh [12,13].

Organoleptic evaluation by consumers is a practical and cost-effective method to evaluate the freshness of agricultural products; however, the sensory information is affected by personal preferences, experiences and subjective feelings [14] and in fruit that ripen rapidly there is the risk that its quality can deteriorated prior to sensory and consumer assessments [15].

The use of a low-cost, reliable [16] and chemical-free method [17], that could provide useful information to predict the optimum eating-ripe phase would be a plus to fulfil consumers' preference. An obvious option is the use of the visible-near infrared (Vis-NIR) spectroscopy, since it is one of the most successful non-destructive methods for quality assessment of fruits [18,19] and has been applied to assess the sensory attributes of different products such as apples [20], chicory [21], olive oil [22], cheese [23,24], coffee [25], grapes [26] and tea [27].

The goals of this paper were to use a new approach, the receiver operating characteristic (ROC) analysis, to evaluate and analyse the organoleptic characteristics during storage of two different cultivars, the yellow-fleshed 'Jintao' and the green-fleshed 'Hayward', in three years (seasons); and, besides that, follow-up their spectra evolution along the storage and investigate, attending future work, if typical Vis-NIR spectroscopy could be useful to determine optimum eating-ripe phase, considering the results of the sensory evaluation performed.

2. Material and Methods

2.1. Fruit

Yellow-fleshed kiwifruit (*Actinidia chinensis* Planch cv. Jintao) were harvested from two commercial orchards (41°39′23.6″ N, 8°18′21.6″ W and 41°38′58.2″ N, 8°18′26.0″ W), while kiwifruit *Actinidia deliciosa* (A. Chev.) C.F. Liang et A.R. Ferguson cv. Hayward were harvested in another two (41°37′46.9″ N, 8°23′16.5″ W and 41°37′29.9″ N, 8°19′47.5″ W). All four orchards were located in the Braga region, north Portugal.

After the commercial harvest season, fruit were shipped to the University of Algarve within 2 days and stored at 0 °C in normal atmosphere and relative humidity of 90–95%.

2.2. Sensory Evaluation

The taste panels were carried out by people recruited from faculty staff and students, which were trained to be familiar with such type of panels. These are people which usually participate in the taste panels carried out at the faculty. Groups with 15 to 32 elements, according to their availability due to COVID-19 times, performed the sensory evaluations based on a 7-point hedonic scale (1 = dislike extremely, 2 = dislike, 3 = slightly dislike, 4 = neither like nor dislike, 5 = slightly like, 6 = like, 7 = like very much) [28], for the following parameters: fruit appearance, pulp appearance, aroma, texture, sweetness, acidity, and general taste. In general, all parameters were evaluated after 2.5 and 4.5 months of storage for 'Jintao' kiwifruit and after 2.5, 4.5 and 5.5 months for 'Hayward' kiwifruit. In 2020, 'Hayward' kiwifruit parameters were only evaluated once due to COVID-19 pandemic. The storage time considered for both cultivars was according to their usual storage capacity, up to 5 months for 'Jintao' and 6 for 'Hayward' [29]. All fruit presented to the sensory panellists were at room temperature.

2.3. Spectroscopy

To follow-up spectra evolution during storage, eight fruit, from each cultivar, were drawn every 15 days. The temperature was registered with an infrared handheld digital thermometer EEM100 (Perel, Velleman, Belgium) and three Vis-NIR spectra acquired from each unpeeled kiwifruit, along the equatorial area, in a setup similar to the one described by Cavaco et al. [30], using a Vis-NIR spectrometer USB4000 (Ocean Optics, Orlando, FL, USA), working in the range 345–1037 nm, with an integration time of 20 msec and

50 averages, a light source LS-1-LL (Ocean Optics, Orlando, FL, USA), a bifurcated fibre with an interactance probe FCR-7UVIR400–2-BX/ME (Avantes, Apeldoorn, The Netherlands) held at a constant height above the fruit flesh (0.47 mm, through the use of a spacer) and a disk of Spectralon white surface (WS-1, Ocean Optics, Orlando, FL, USA) used as reference material.

Due to unavailability of the previous equipment, in 2019 and 2020, the spectrometer was replaced by AvaSpec-Mini2048CL (Avantes, Apeldoorn, The Netherlands), working in the range 145–1100 nm, integration time 1.2 msec and 50 averages, the light source by AvaLight-HAL-S-Mini (Avantes, Apeldoorn, The Netherlands) and the reference material by WS-2 reference tile (Avantes, Apeldoorn, The Netherlands).

It is essential to inquire about the impact of changing the spectrometer model on result consistency. In the realm of quantitative predictions in regression, it is widely recognized that replacing the spectrometer necessitates a process known as calibration transfer. Calibration transfer is a common procedure in chemometrics [31] and is frequently employed in fruit models, including kiwifruit [32,33]. This is due to the fact that even minor variations in the spectral shape can result in significant shifts in predictions. However, the purpose of the spectroscopic measurements in this study is to identify patterns and correlations in reflectance. Consequently, slight variations introduced by the spectrometer model do not alter the shape of the plots.

2.4. Internal Quality Attributes

After spectroscopic measurements, pulp firmness was determined by puncture with a texturometer (Chatillon TCD200, Digital Force Gauge DFIS 50, John Chatillon & Sons, Inc., Somerset Drive Largo, FL, USA) using a cylinder probe of 8 mm at a depth of 7 mm, at equatorial level in both sides. Then, 3 mm thick kiwifruit equatorial slices (1 per fruit) were cut, weighed and dried at 105 °C until constant weight for determination of dry matter (DM), expressed as percentage of dry weight relatively to fresh weight (%). The remaining of the kiwifruit were peeled and squeezed. The juice filtered by a cotton cloth was used for the measurements of SSC and titratable acidity (TA).

The SSC was determined by using a digital refractometer HI 96801 (Hanna Instruments, Woonsocket, RI, USA) and expressed as %. Total TA, expressed as mass percentage of citric acid per 100 mL juice (%), was determined by a TitroLine 6000 (SI Analytics, Mainz, Germany), using 2 mL kiwifruit juice diluted with 8 mL distilled water, and titrated with 0.1 M NaOH until a pH of 8.2.

Quality measurements were performed according to the AOAC [34].

2.5. Data Analysis

The descriptive statistical analysis of the quality attributes and sensory evaluation was performed in IBM SPSS Statistics 27 (IBM Corp., Armonk, NY, USA). Mann–Whitney independent nonparametric test was applied and a Kruskal–Wallis the non-parametric ANOVA was performed to test the significant differences between the mean ranks among the storage time, in different years. Pairwise comparisons to observe the differences and descriptive statistics based on median, minimum, maximum, range and interquartile range were also performed.

A non-metric multidimensional scaling plot method using the ALSCAL algorithm in a 7-point Likert scale was applied. This method performs multidimensional scaling of proximity or distance-like [35], and the results are represented in a cartesian plane, where each axis may be used for representing the overall position in the panellists' mind. Multidimensional scaling refers to models that analyse distances between objects, having applied the Euclidian distances algorithm. Points are arranged in such a way that the geometrical distance between them will reflect empirical relationships in the data.

The most desirable property of receiver operating characteristic (ROC) analysis is that the accuracy indices derived from this technique are not distorted by fluctuations caused by decision criteria. For the application of this procedure, the "*General taste*" variable, evaluated by the panellist's questionnaire, was considered in binary terms (1 = 7-point attribute of the maximum value and 0 = others). A model with a value above 0.5 is considered good, while a value less than 0.5 is no better than random prediction. This classification method is presented only as an accessory and complementary analysis tool.

The spectral data analysis was performed in MATLAB R2019a, version 9.6 (The MathWorks, Inc., Natick, MA, USA). Normalization procedure was used to pre-process the spectra acquired from the kiwifruit.

3. Results and Discussion

3.1. Sensory Evaluation

3.1.1. 'Jintao' Kiwifruit

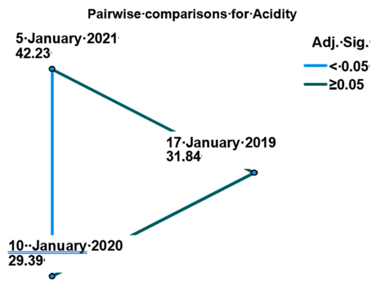
The median for kiwifruit *Actinidia chinensis* 'Jintao' was around a six-point Likert scale for all sets and along the time, and the interquartile range, as a measure of dispersion, had low values as described in Table 1, between 0 and 3, for most cases. The maximum obtained was seven-point and the minimum value was 2.

Table 1. Descriptive statistics for *Actinidia chinensis* 'Jintao' kiwifruit according to panellist's evaluation.

Storage Days	Month and Year	Parameter	Median	Minimum	Maximum	Range	Inter Quartile Range
74	January 2019	Fruit Appearance	6	4	7	3	1
		Pulp Appearance	6	3	7	4	1.25
		Aroma	5.5	3	7	4	1.25
		Texture	6	5	7	2	1.25
		Sweetness	6	2	7	5	1
		Acidity	6	2	7	5	3
		Global Taste	6	5	7	2	1.25
132	March 2019	Fruit Appearance	6	5	6	1	0
		Pulp Appearance	6	4	7	3	0
		Aroma	6	3	6	3	1
		Texture	5	2	7	5	2
		Sweetness	6	4	7	3	1
		Acidity	6	4	7	3	3
		Global Taste	6	2	7	5	1
75	January 2020	Fruit Appearance	6	4	7	3	1
		Pulp Appearance	6	4	7	3	2
		Aroma	6	4	7	3	1
		Texture	6	3	7	4	2
		Sweetness	6	3	7	4	2
		Acidity	6	2	7	5	3
		Global Taste	6	3	7	4	2
131	March 2020	Fruit Appearance	6	2	7	5	0.75
		Pulp Appearance	6	3	7	4	0.75
		Aroma	6	3	7	4	1
		Texture	6	2	7	5	0.75
		Sweetness	6	2	7	5	2
		Acidity	6	3	7	4	1.75
		Global Taste	6	2	7	5	1.75
70	January 2021	Fruit Appearance	7	3	7	4	1
		Pulp Appearance	6	3	7	4	2
		Aroma	6	4	7	3	2
		Texture	6	2	7	5	1
		Sweetness	6	5	7	2	1
		Acidity	6	4	7	3	1
		Global Taste	7	4	7	3	1
127	March 2021	Fruit Appearance	6	3	7	4	1
		Pulp Appearance	6	3	7	4	1
		Aroma	6	3	7	4	2
		Texture	6	5	7	2	1
		Sweetness	6	4	7	3	2
		Acidity	6	4	7	3	2
		General Taste	6	4	7	3	1

In fact, for all the three years, independently of the month, all parameters evaluated were very consistent with a six-point evaluation through time and through years, meaning that 'Jintao' kiwifruit were very appreciated by the panellists regardless of being kept in storage for 2.5 or 4.5 months at 0 °C; however, for *Actinidia chinensis*, the storage period, at low temperature, is, usually, four months or less [36].

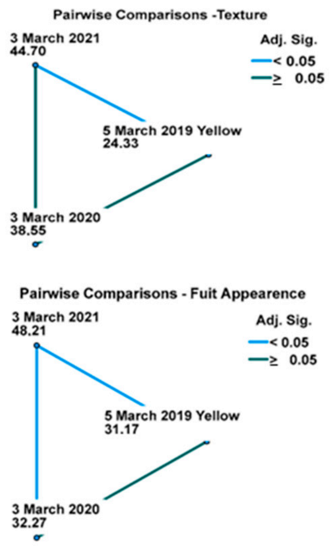
Pairwise comparisons for the same months in different years were performed revealing differences only for acidity between January 2020 and January 2021 (Figure 1), texture between March 2019 and March 2021, fruit appearance between March 2021 and March 2019, as well March 2021 and March 2020 (Figure 2).



Null Hypothesis	Sig.	Decision[a,b]
The distribution of Fruit Appearance is the same across years	0.449	Retain the null hypothesis.
The distribution of Pulp Appearance is the same across years	0.628	Retain the null hypothesis.
The distribution of Fruit Aroma is the same across years	0.920	Retain the null hypothesis.
The distribution of Texture is the same across years	0.266	Retain the null hypothesis.
The distribution of Sweetness is the same across years	0.591	Retain the null hypothesis.
The distribution of Acidity is the same across years	0.040	Reject the null hypothesis.
The distribution of General Taste is the same across years	0.087	Retain the null hypothesis.

a. The significance level is 0.050.
b. Asymptotic significance is displayed.

Figure 1. Pairwise Comparisons for acidity and table of Independent-Samples Kruskal–Wallis test results for 'Jintao' kiwifruit.



Null Hypothesis	Sig.[a,b]	Decision
The distribution of Fruit Appearance is the same across date.	0.002	Reject the null hypothesis.
The distribution of Pulp Appearance is the same across date.	0.169	Retain the null hypothesis.
The distribution of Fruit Aroma is the same across date.	0.311	Retain the null hypothesis.
The distribution of Texture is the same across date.	0.008	Reject the null hypothesis.
The distribution of Sweetness is the same across date.	0.367	Retain the null hypothesis.
The distribution of Acidity is the same across date.	0.550	Retain the null hypothesis.
The distribution of General Taste is the same across date.	0.282	Retain the null hypothesis.

a. The significance level is 0.050.
b. Asymptotic significance is displayed.

Figure 2. Pairwise Comparisons for fruit appearance and texture, and table of Independent-Samples Kruskal–Wallis test results for 'Jintao' kiwifruit.

Further analysis was performed applying MDS by year and by month (Figure 3). The results show that pulp appearance and fruit appearance are always linked, as well as general taste and sweetness, except in March 2020, meaning that, overall, the fruit appearance reflects on pulp appearance and sweetness has an impact on taste.

The degree of ability to explain the results of MDS were analysed through STRESS-I values (Table 2). Since STRESS-I values were below 25%, the error rate is also still below the fair value. The value of 90 and upper percent in the RSQ value (R-Squared is a statistical measure of how close the data are to the fitted regression line), show that the results of MDS analysis on consumers' taste can be well explained (Table 2).

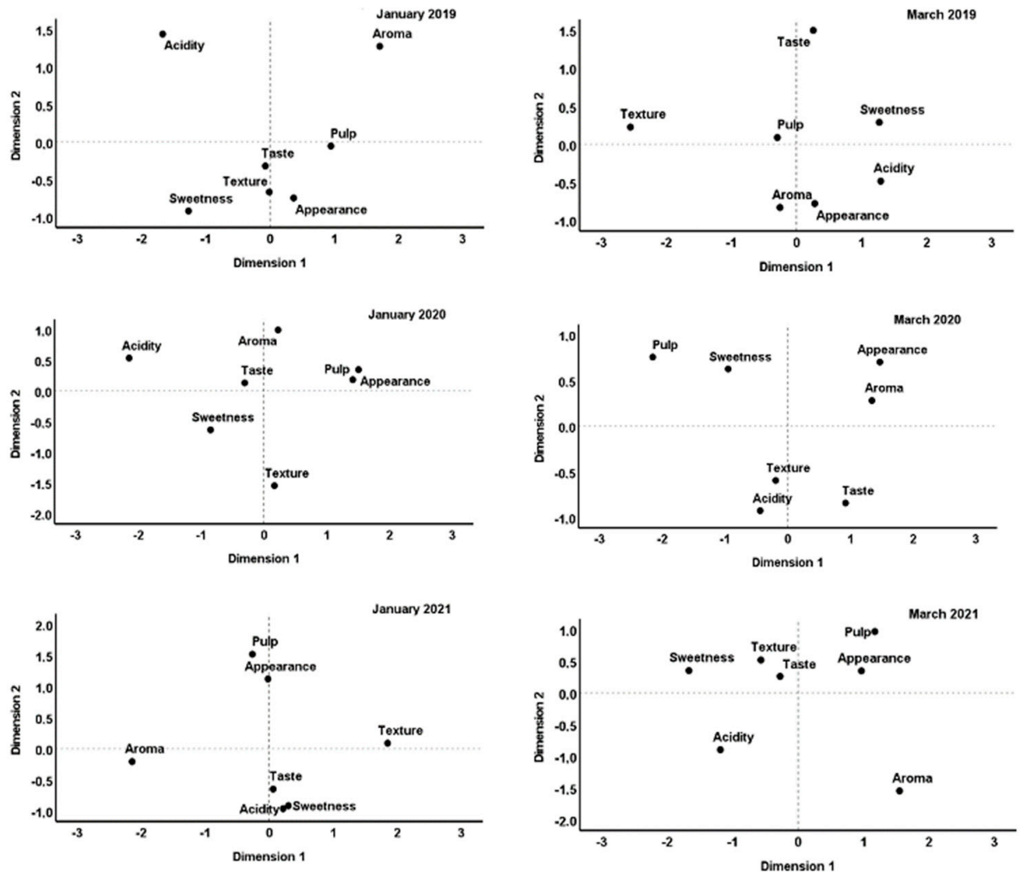


Figure 3. MDS (Multidimensional scaling) diagrams showing the Euclidean distance method between the perceptions of consumer's taste in *Actinidia chinensis* 'Jintao' kiwifruit.

Table 2. Values of STRESS-I and RSQ for MDS ALSCAL methodology.

Storage Days	Month and Year	STRESS-I Value	RSQ Value
74	January 2019	0.025	0.985
132	March 2019	0.060	0.994
75	January 2020	0.076	0.894
131	March 2020	0.135	0.961
70	January 2021	0.032	0.979
127	March 2021	0.047	0.997

3.1.2. 'Hayward' Kiwifruit

For 'Hayward' kiwifruit the median was around six-point Likert scale for all sets and along the time, and the interquartile range, as a measure of dispersion, had low values between 0 and 3 (Table 3), although a little more irregular than 'Jintao' possibly due a higher number of sensory evaluations and a longer storage time. The maximum obtained was seven-point and the minimum value was one-point.

Table 3. Descriptive statistics for 'Hayward' kiwifruit according panellist's evaluation.

Storage Days	Month and Year	Parameter	Median	Minimum	Maximum	Range	Inter Quartile Range
74	February 2019	Appearance	7	6	7	1	0.5
		Pulp	6	6	7	1	1
		Aroma	6	4	7	3	2
		Texture	6	2	7	5	0
		Sweetness	5	2	7	5	1
		Acidity	6	3	7	4	2
		Taste	6	3	7	4	1.5

Table 3. *Cont.*

Storage Days	Month and Year	Parameter	Median	Minimum	Maximum	Range	Inter Quartile Range
131	April 2019	Appearance	7	5	7	2	1
		Pulp	6	5	7	2	1
		Aroma	5.5	3	7	4	1
		Texture	6	5	7	2	1
		Sweetness	5	2	7	5	1.75
		Acidity	5.5	2	7	5	2.5
		Taste	6	2	7	5	1
172	May 2019	Appearance	6.5	5	7	2	1
		Pulp	6	6	7	1	1
		Aroma	6	4	7	3	1
		Texture	6	4	7	3	1
		Sweetness	6	2	7	5	1.75
		Acidity	5.5	2	7	5	2.75
		Taste	6	3	7	4	1
61	January 2020	Appearance	6	5	7	2	1
		Pulp	7	4	7	3	1
		Aroma	6	3	7	4	1
		Texture	6	2	7	5	1
		Sweetness	5	2	7	5	3
		Acidity	5	2	7	5	3
		Taste	6	2	7	5	2
53	January 2021	Appearance	6.5	5	7	2	1
		Pulp	7	5	7	2	1
		Aroma	6	4	7	3	1.25
		Texture	6	4	7	3	0.5
		Sweetness	5	1	7	6	2
		Acidity	5	1	7	6	1.25
		Taste	6	1	7	6	1
123	March 2021	Appearance	6	5	7	2	1
		Pulp	6	5	7	2	1
		Aroma	6	4	7	3	1
		Texture	7	3	7	4	1
		Sweetness	6	1	7	6	1
		Acidity	6	1	7	6	2
		Taste	6	3	7	4	1
152	April 2021	Appearance	6	4	7	3	1
		Pulp	6	4	7	3	1
		Aroma	6	4	7	3	2
		Texture	7	5	7	2	1
		Sweetness	6	5	7	2	1
		Acidity	6	3	7	4	2
		Taste	6	5	7	2	1

Considering the homologous months of sampling, statistical differences were found, with the application of the Mann–Whitney nonparametric test for two independent samples, between April 2019 and April 2021 for sweetness and overall taste ($p < 0.05$) (Table 4). Although the sensory evaluations mentioned were performed at the same month, in the last one the kiwifruit were in storage 20 days more than in 2019, what possibly was enough to cause the statistically difference. As climacteric fruit, kiwifruit ripen through storage reaching the eating-ripe stage faster or latter according to their main ripening parameters at harvest time, which are SSC and Firmness [37]. The evolution of these parameters depends, not only of the harvest period, but also of pre and postharvest storage conditions [2,7]. In our case, there were both effects which explain the differences, mainly at the end of storage.

Table 4. Mann–Whitney independent test applied in 'Hayward' kiwifruit sweetness and general taste evaluation.

Parameter	Group Date	N	Mean Rank	Sum of Ranks	Probability
Sweetness	April 2019	17	13.82	235	<0.001
	April 2021	24	26.08	626	
	Total	41			
Taste	April 2019	17	14.88	253	0.003
	April 2021	24	25.33	608	
	Total	41			

The MDS analysis shows that for 'Hayward', as 'Jintao', pulp appearance and fruit appearance, and also general taste and sweetness are always linked (Figure 4).

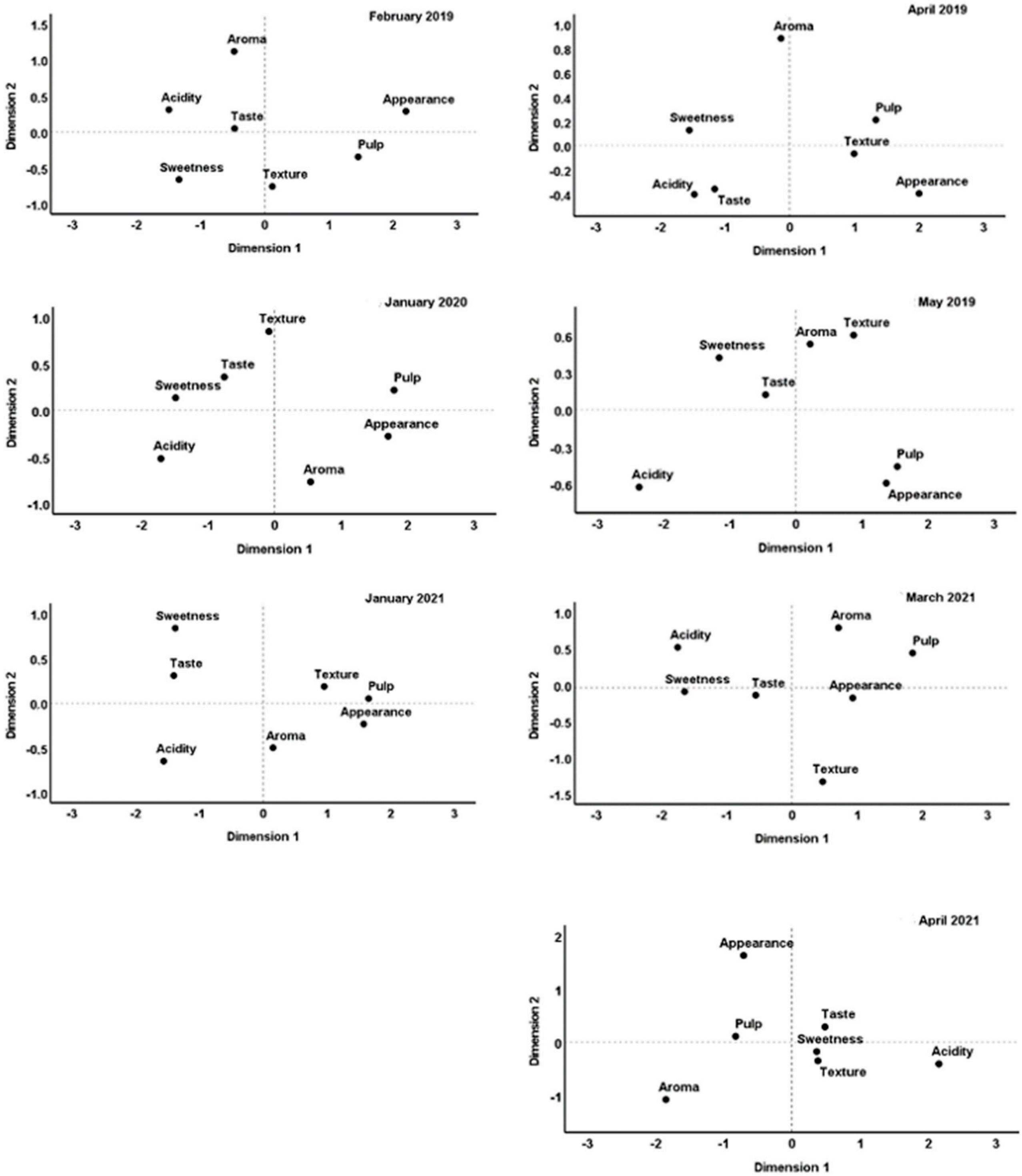


Figure 4. MDS (Multidimensional scaling) diagrams showing Euclidean distance method between the perceptions of consumer's taste in 'Hayward' kiwifruit.

3.1.3. ROC Analysis

Performing a receiver operating characteristic (ROC) analysis along time by each sensory evaluation, showed that, for both cultivars, sweetness and acidity were the variables that respond with better scores for General taste (Figure 5), confirming that these two parameters are crucial factors for consumer acceptance [9,11]. However, for 'Jintao', aroma seems to be important for global taste in January and March 2020, and also appearance in March 2020 and texture in March 2021. For 'Hayward', texture had also impact in May 2019 and pulp appearance in April 2021, perhaps due to over-ripeness.

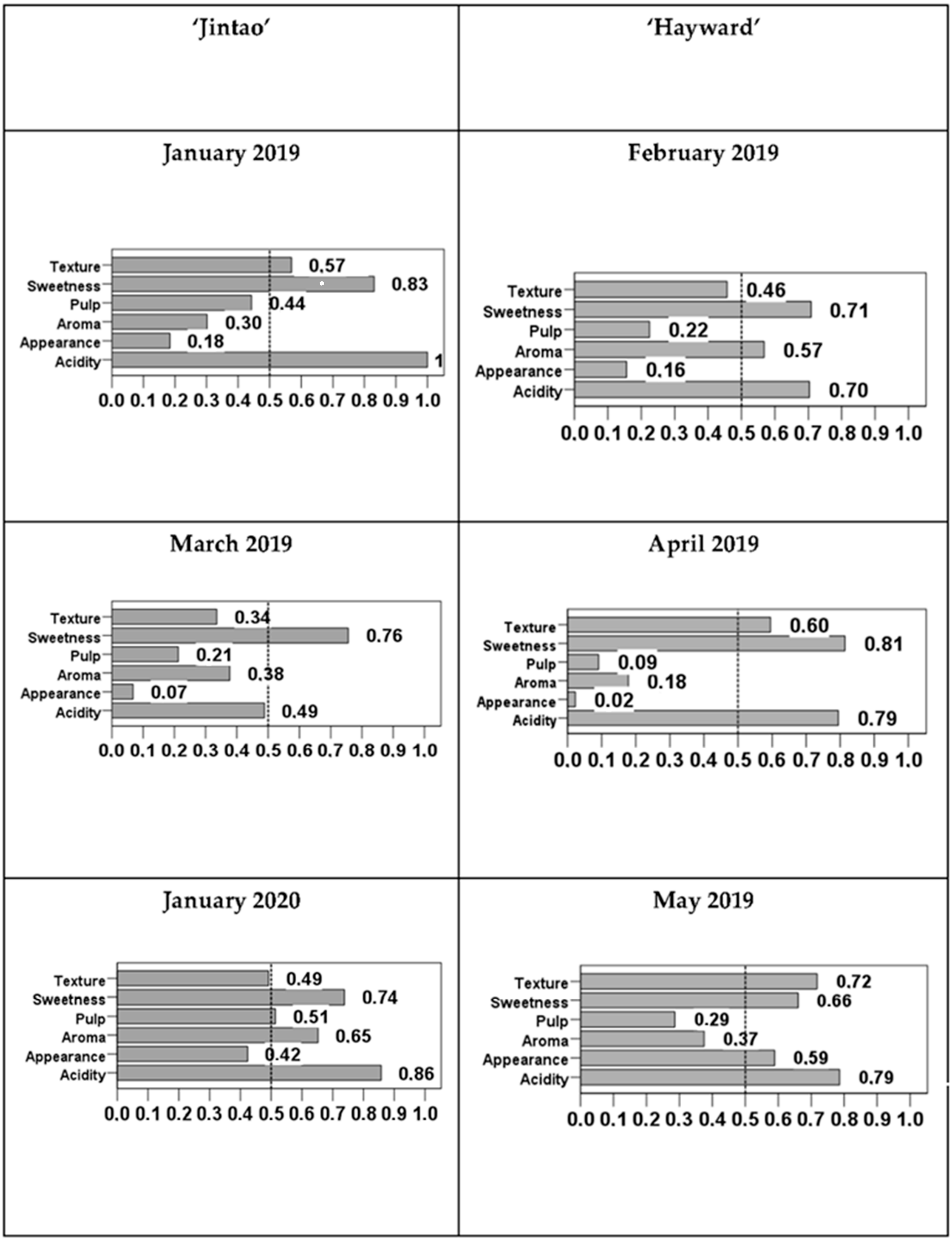


Figure 5. *Cont.*

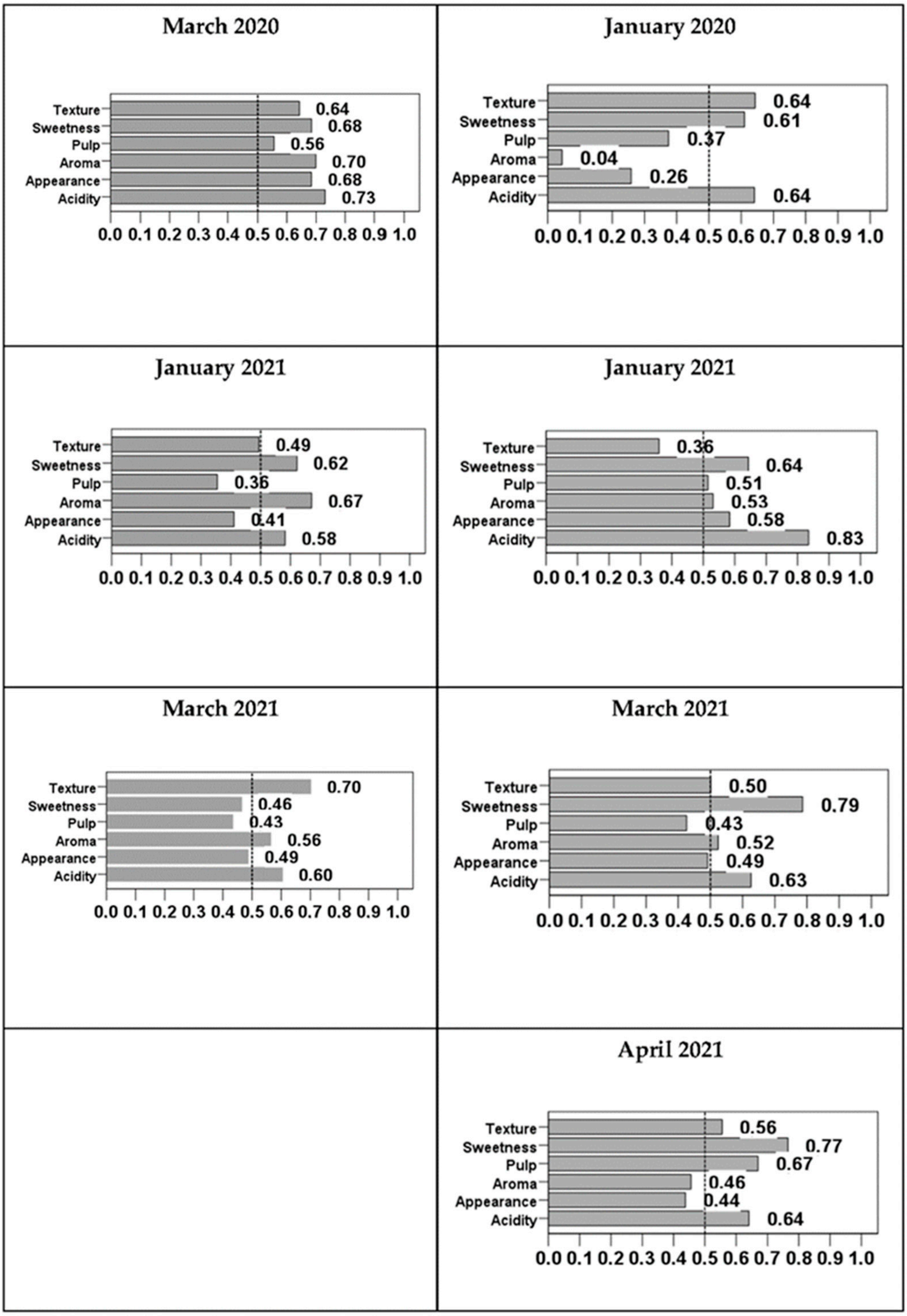


Figure 5. Model quality for ROC curve analysis with tasters' variables according to General taste maximum value given (seven-point) and the perceptions of consumer's taste in kiwifruit ('Jintao' on the left and 'Hayward' on the right).

Instead of applying the ROC analysis for each month and year, ROC can be performed to obtain an overall model quality. This approach reveals that, for both cultivars, sweetness, acidity and texture were the variables that respond with better scores for General taste. Aroma has also importance for the General taste on 'Jintao' (Figure 6).

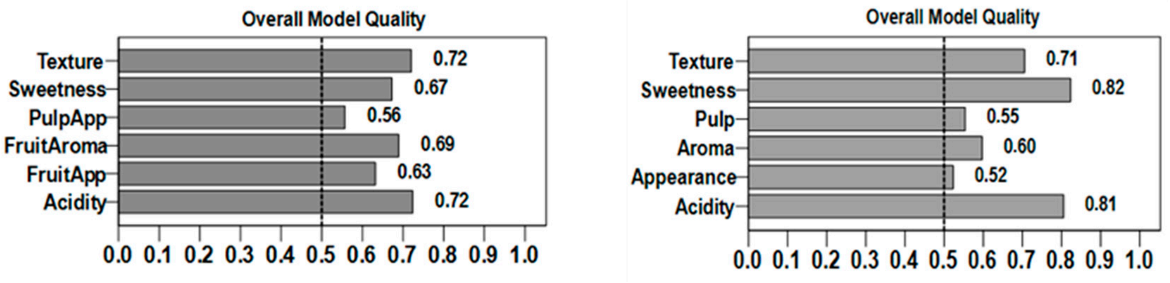


Figure 6. Global Model quality for ROC curve analysis with tasters' variables according to General taste maximum value given (7-point) at kiwifruit ('Jintao' on the left and 'Hayward' on the right).

These results confirm, in first place, that, for each cultivar, sensory evaluation depends on different attributes. For example, for 'Golden Delicious' apples, values of firmness, SSC and TA are important, while for 'Elstar' apples consumer acceptance is more dependent on aroma and juiciness [38,39]; in second, that sweetness, acidity and aroma are critical to consumer acceptance of kiwifruit [9,11,14].

3.2. Average Spectra Temporal Evolution of Cold Stored Kiwifruit

In order to compensate for reflectance variations due to pulp texture variations, the absorption spectra were normalized to 800 nm (the NIR plateau), with the additional advantage that the ratio of reflectance at 680 nm to that of 800 nm provides a normalized proxy for chlorophyll content. The transformed spectra were then averaged over each measurement day, to provide possible spectral patterns. These are represented in Figure 7 for 'Jintao' and in Figure 8 for 'Hayward' kiwifruit. There was not a consistent evolution pattern of the spectra in the three years.

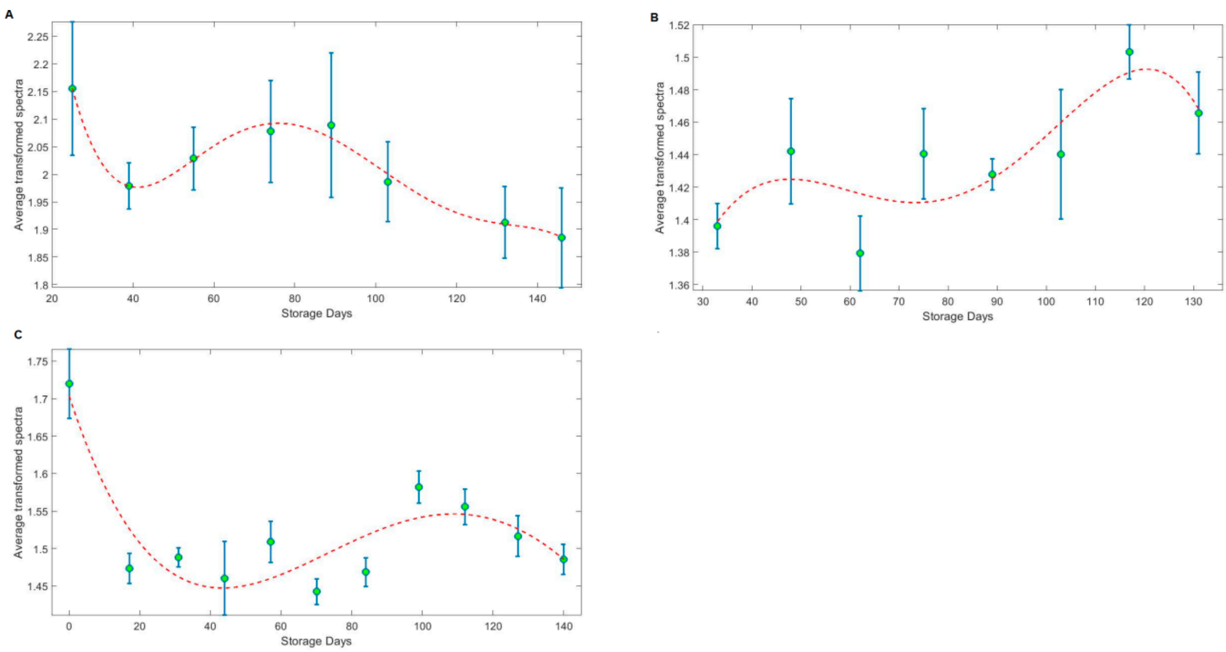


Figure 7. Averaged values of A_{680}/A_{800} from Vis-NIR spectra of kiwifruit acquired along storage time for 'Jintao' kiwifruit during: (**A**) 2018/2019; (**B**) 2019/2020; (**C**) 2020/2021. Data depicted are the Mean ± SE of eight kiwifruit.

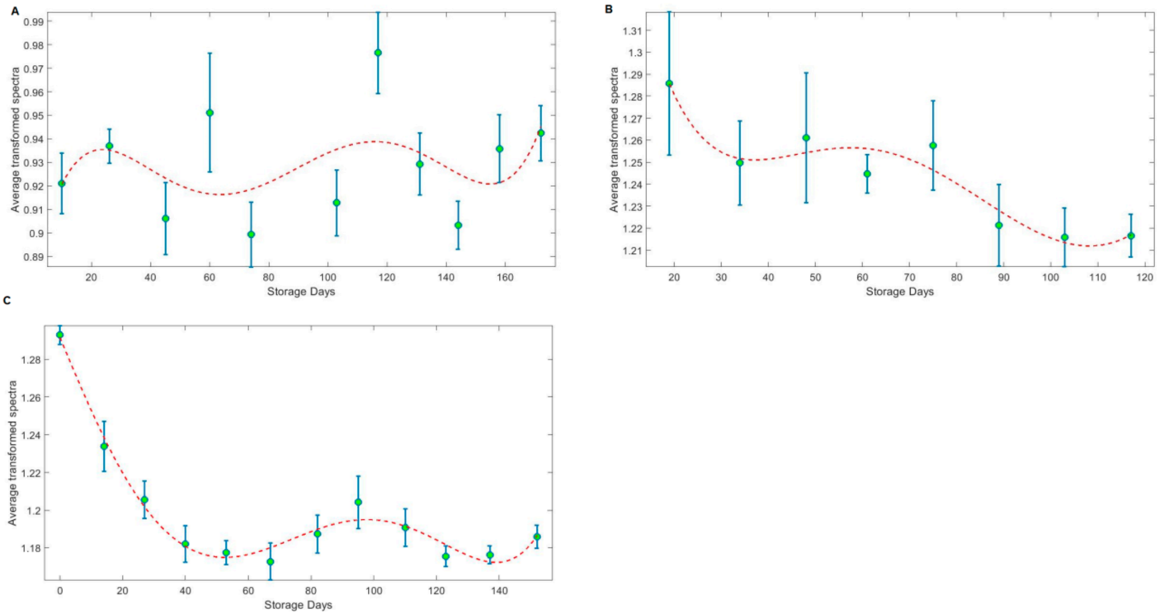


Figure 8. Averaged values of A_{680}/A_{800} from Vis-NIR spectra of kiwifruit acquired along storage time for 'Hayward' kiwifruit during: (**A**) 2018/2019; (**B**) 2019/2020; (**C**) 2020/2021. Data depicted are the Mean ± SE of eight kiwifruit.

Since A_{680}/A_{800} is a proxy for chlorophyll content, it can be seen in four of the six graphs in Figures 7 and 8 that it decreases, as expected. However, in two other cases it remains approximately constant or even tends to rise. Even in the expected cases, that show the global decrease, there are modulations in time, which have to do simultaneously with the variation in chlorophyll and fruit firmness.

Being that firmness is an internal quality attribute (IQA) that consistently decreases with storage time, it could be expected that with the loss of kiwifruit firmness, the reflectance would be lower since soft fruit has less scattering (meaning also an equivalent absorption higher). However, the turbid biological material complicates the absorption and scattering processes and the complexity and the heterogeneities of the fruit's tissue [16,40] affects the relationship between the reflectance spectra and the mechanical properties [18,41]. Furthermore, it was reported in apples that cell wall degradation reduces the scattering events [42], but air-filled pores caused by cells water loss leads to an increase in them [43], which also complicates this relation [38]. Moreover, since kiwifruit of each cultivar were from two different orchards and not from the same batch, an extra complexity might have been added.

Despite all these difficulties, the spectra collected show differences along the storage time, meaning that Vis-NIR spectroscopy is able to identify chemical and physical changes that occur during kiwifruit ripening in cold storage.

3.3. Spectra Reflectance Correlation with Internal Quality Attributes

Sweetness and texture have a major impact in consumer acceptance, for both cultivars, according the sensory evaluation results. Those two parameters are correlated to SSC (°Brix) and firmness, respectively [18]. For this reason, we investigated if there is a good correlation between kiwifruit SSC and firmness and their reflectance spectra acquired during storage, and at which wavelength.

3.3.1. Soluble Solids Content (SSC)

In the first place, correlation between kiwifruit SSC and their reflectance spectra was showed to be very different in each year/season. Even to the point that, in one year (2018/2019), there is a good positive correlation, and in the other two, although not so relevant, the correlation is negative for the same wavelength range (500–800 nm), while in

800–950 nm, the correlation inverted in all seasons (Figure 9A). Although very irregular through years, for 'Jintao' kiwifruit the higher correlation was obtained in the range 650–710 nm ($\geq$0.8), followed by the range 820–950, in 2018/2019. The latter range revealed to have a negative correlation with 'Hayward' SSC also for kiwifruit from 2018/2019 (Figure 9B). There was also a good correlation, but positive, in the range 730–780 nm for the previous season, and a negative one between 635–690 nm in 2020/2021.

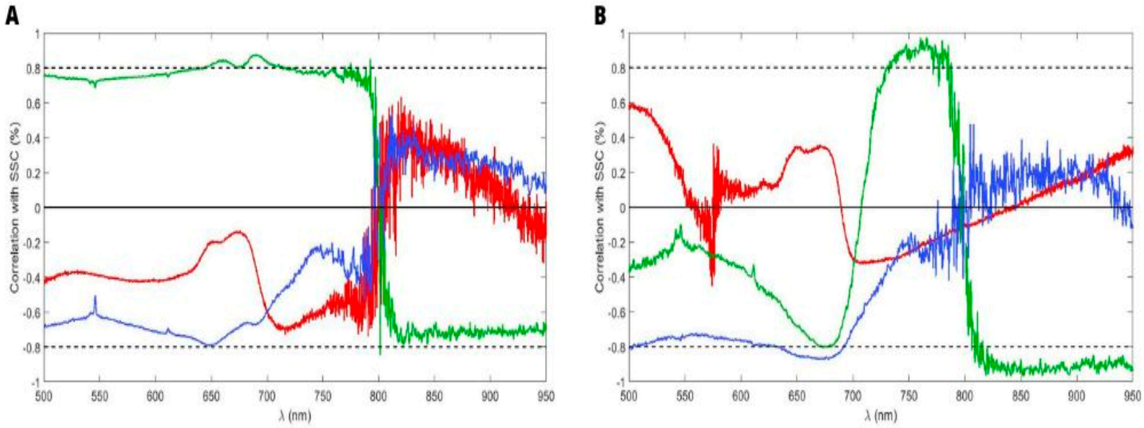


Figure 9. Correlation between soluble solids content (SSC) and Vis-NIR reflectance spectra of: (**A**) 'Jintao' kiwifruit; (**B**) 'Hayward' kiwifruit. Each colour line represents a different year/season (red = 2018/2019; green = 2019/2020; blue = 2020/2021).

Results showed a very irregular correlation between SSC and reflectance spectra, but there is, effectively, wavelength ranges with good correlation values, meaning that Vis-NIR spectroscopy can be used to predict SSC of kiwifruit during storage with special attention to 635–780 nm, and so the kiwifruit consumers' preference.

3.3.2. Firmness

Correlation values between reflectance spectra and 'Jintao' firmness are totally opposite in the two years showed (Figure 10A). The only relevant correlation was found at 695–720 nm in 2018/2019. In the case of 'Hayward' kiwifruit, correlation between firmness and reflectance spectra is even more irregular, not only between seasons, but also along the wavelengths in the same year (Figure 10B). There is a good positive correlation in the range 500–705 nm in 2020/2021 and at 810–950 nm in 2019/2020. A negative correlation was found at 740–785 nm in 2019/2020.

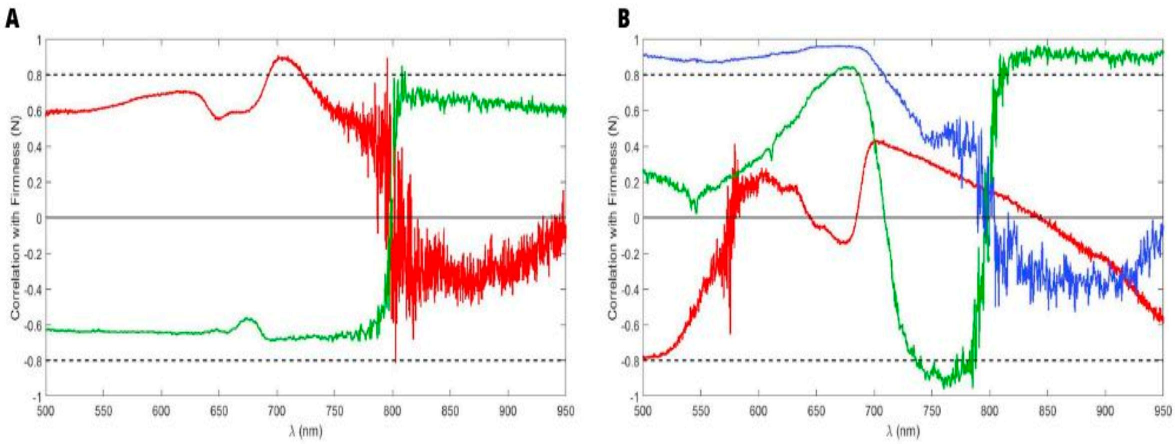


Figure 10. Correlation between firmness and Vis-NIR reflectance spectra of: (**A**) 'Jintao' kiwifruit; (**B**) 'Hayward' kiwifruit. Each colour line represents a different year/season (red = 2018/2019; green = 2019/2020; blue = 2020/2021).

3.3.3. Other Internal Quality Attributes

Considering the results above, further investigation was performed to analyse other internal quality attributes and a good correlation with reflectance spectra was found for 'Jintao' kiwifruit dry matter (Figure 11A) and, not so good but still relevant, for titratable acidity (Figure 11B).

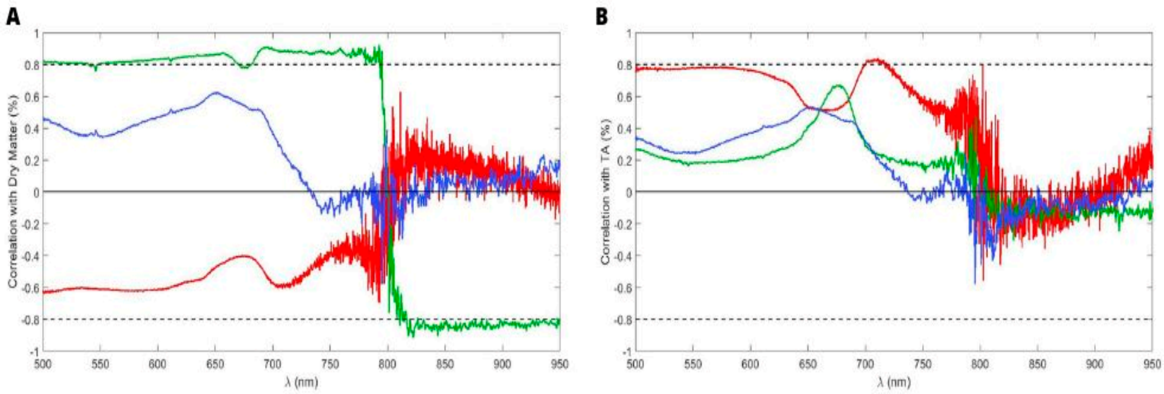


Figure 11. Correlation between Vis-NIR reflectance spectra of 'Jintao' kiwifruit and: (**A**) Dry matter; (**B**) Titratable acidity (TA). Each colour line represents a different year/season (red = 2018/2019; green = 2019/2020; blue = 2020/2021).

Correlation between dry matter of 'Jintao' kiwifruit and reflectance spectra acquired during storage is, in fact, very similar with the correlation showed for SSC in 2019/2020, highlighting the high correlation ($\geq$0.8) at almost all spectrum of this year, which was positive at 550–665 nm and 685–790 nm, and negative at 820–950 nm.

On the other hand, although titratable acidity showed only a high positive correlation at 700–715 nm, correlation between 500–595 nm is very close to 0.8 in 2018/2019.

4. Conclusions

In this work, applying the receiver operating characteristic (ROC) analysis to sensory evaluation performed during cold storage of two kiwifruit cultivars, through three years, reveal that for 'Jintao' and 'Hayward' kiwifruit sweetness, acidity and texture were the variables, with higher impact scores in kiwifruit General taste through cold storage. For 'Jintao' aroma was also an important attribute. Although 'Jintao' kiwifruit was slightly higher appreciated by consumers than 'Hayward', both cultivars were highly appreciated.

Since the Vis-NIR spectroscopy showed to be able to distinguish the chemical and physical changes that occur during kiwifruit ripening in cold storage and there are good correlation values between SSC and reflectance spectra at the 635–780 nm wavelength range, this technology could be an objective alternative to determine optimum eating-ripe stage, which need further research to be consolidated.

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