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ORIGINAL RESEARCH PAPER

PHYSICOCHEMICAL COMPOSITION OF PERSIMMONS: A NON-DESTRUCTIVE DETERMINATION APPROACH

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Abstract

Fruit from eight persimmon (*Diospyros kaki*) cultivars were evaluated for physicochemical quality at physiological maturity, and classification models were developed using near-infrared spectroscopy (Vis-NIR). Physical traits (mass, diameter, height), color (L*, a*, b*, chromaticity), firmness, soluble solids content, pH, titratable acidity, moisture, and dry matter were evaluated. Vis-NIR Spectra (310–1100 nm) were collected on a subset of five cultivars (n = 20 fruits), preprocessed with SNV, MSC, and Savitzky–Golay derivatives, and analyzed by PCA and PLS-DA; ANOVA supported comparisons. Pomelo showed higher fruit mass and diameter. Giombo and Taubaté had higher L* values and SSC and TA did not differ significantly between cultivars. Moisture content was highest and DM lowest in hybrid 82, while Giombo showed the lowest firmness. PCA explained 91–97% of spectral variance without clear separation across cultivars. PLS-DA achieved the best validation for Rama Forte (R^2_V = 0.75; $RMSE_V$ = 0.21) and Giombo (R^2_V = 0.68; $RMSE_V$ = 0.25). Vis-NIR spectroscopy successfully classified two persimmon cultivars, which can possibly be used for authentication of the product offered to consumers.

Keywords: *Diospyros kaki*, VIS-NIR spectroscopy; chemometrics, postharvest

Introduction

According to FAO (2020), global persimmon *Diospyros kaki* L. production reached 4,241,366 metric tons (t) in 2020, representing 0.75% of the total world fruit production (Direito *et al.*, 2021). This species belongs to the Ebenaceae family, a

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significant pantropical tree genus globally distributed across warm climates, with major cultivation areas including China, Korea, Japan, Australia, Pakistan, India, and Brazil (Rauf *et al.*, 2017).

Persimmon is native to Asia, primarily China and Japan, and has since been successfully dispersed to temperate and subtropical regions worldwide. This species is primarily cultivated for its fruit, but it is also valued for its wood and dyes, establishing a strong focus on commercial production. Other species, such as *Diospyros virginiana*, *Diospyros oleifera*, and *Diospyros lotus*, are also relevant to the genus (Martins and Pereira, 1989).

The fruit itself is a berry, exhibiting varied shapes that range from ovoid to globular or flattened. The skin color varies from yellow to red, and the pulp is typically yellowish, with or without seeds. The presence or absence of seeds can sometimes alter the fruit's color, size, and flavor (Simão, 1998). Ripe persimmon pulp is characterized by a gelatinous and soft texture, mainly composed of mucilage and pectin (Sato and Assumpção, 2002).

As a climacteric fruit, persimmon exhibits high respiration and ethylene rates, which promote desirable changes during ripening, such as changes in color, pulp firmness, carbohydrate profile, organic acids, and soluble proanthocyanidins in non-astringent cultivars (Kluge and Tessmer, 2018). Fruit ripening is a sequence of complex physiological, biochemical, and structural transformations. During this process, the high concentration of tannins in unripe fruit gradually decreases, and chlorophyll is degraded, leading to a more yellowish appearance. These compounds are simultaneously transformed into sugars or consumed via respiration as the fruit matures. Due to the accumulation of carotenoids, the ripe fruit color shifts toward orange, reddish-orange, or deep red (Matheus *et al.*, 2020; Tessmer *et al.*, 2016).

Ripe persimmons are non-acidic and are rich in starch, glucose, minerals, particularly potassium (K), vitamins A and C. Numerous studies, as recently reviewed by Pérez-Piñero *et al.* (2024), have demonstrated that persimmon consumption is associated with anti-tumor, anti-hypercholesterolemic, and antidiabetic effects. These significant health benefits are primarily linked to the fruit's richness in antioxidants, including vitamins, phenolic compounds, and carotenoids.

Persimmon cultivars are commonly classified into three types based on tannin presence: astringent (“sibugaki”), pollination-variant (“sibugaki variant” or “variant amagaki”), and non-astringent (“amagaki”). Astringent cultivars typically have yellowish flesh with high soluble tannin content and may or may not contain seeds; they generally require postharvest de-astringency treatments to be palatable. In Brazil, several cultivars, such as ‘Taubaté’, ‘Pomelo’, and ‘Rubi’, belong to this astringent group (Campo-Dell’Orto *et al.*, 1996; Blum *et al.*, 2008; Martins and Pereira, 1989).

These cultivars have distinct morphological and physicochemical characteristics (Martins and Pereira, 1989). However, the identification of different cultivars can be challenging for consumers, especially when fruits exhibit highly similar external traits. Due to the critical need to ensure the identity, guarantee the ideal postharvest ripeness and quality of fruits, various analytical techniques have been implemented. In this context, near-infrared spectroscopy (NIRS) has emerged as a key technology for the non-destructive classification and quality assessment of various fruits (Amodio *et al.*, 2016; Wei *et al.*, 2020). Research has actively investigated correlations between quality attributes determined using traditional destructive methods with NIRS, aiming to enable the quantification and prediction of internal quality characteristics without the need for destructive evaluations (Amorim *et al.*, 2024).

Therefore, the objective of this study was to evaluate the feasibility of portable Vis–NIR spectroscopy for rapid non-destructive discrimination of eight persimmon cultivars using principal component analysis (PCA) and partial least squares discriminant analysis (PLS-DA) based on physicochemical parameters.

Materials and methods

Plant material

Fruit was obtained from the persimmon orchard located at the São Paulo State University (UNESP), Faculty of Agricultural and Veterinary Sciences (FCAV), Jaboticabal Campus, Jaboticabal, São Paulo State, Brazil (21°15’22” S and 48°18’58” W, and at an altitude of 560 m). The persimmon trees were 26 years old (11/17/1989), planted 7.0 × 4.5 m apart on an open vase system. Fruit from the cultivars ‘Rubi’, ‘Rama Forte’, ‘Pomelo’, ‘Taubaté’, ‘Giombo’, and the hybrids ‘158-7’, ‘82’, and ‘58’ were harvested when fruit color changed from green to yellow-orange (Ebert and Gross, 1985). The color change is commonly used by growers in Brazil as an indicator of maturity stages.

Vis-NIR spectra acquisition

A total of four fruits were randomly selected from the following cultivars: ‘Taubaté’, ‘Rama Forte’, ‘Rubi’, ‘Giombo’,‘Pomelo’, and the fruit from the hybrids ‘158-7’, ‘82’, and ‘58’, totaling 32 persimmons. Two spectra were collected on both sides of each fruit using the F-750 portable spectrometer (Felix Instruments, Washington, USA). The Vis-NIR spectra were obtained in the wavelength range of 310 to 1,100 nm at a resolution of 8-13 nm. The spectra were processed using the software Unscrambler®, version X.3 (CAMO, Oslo, Norway).

Reference analysis

Fruit weight

The fruit weight (g) was determined by weighing the fruit on a semi-analytical scale (Shimadzu, model AY 220, Japan) with an accuracy of 0.01 grams. The average of four fruits was used to express this parameter.

Fruit dimensions

A manual caliper (Maub, Poland) was used to measure the length and width of all fruits, which were separated and identified according to each cultivar. These parameters were expressed in centimeters (cm).

Color

A Minolta CR-400 reflectometer (Minolta, Osaka, Japan) was used for this determination. To perform this analysis, four fruits were taken from each cultivar, and two readings were taken from each sample in the central region of the fruits. Fruit color was expressed as lightness (L*), a*, and b*. These values were transformed into chromaticity and hue angle according to McGuire (1992).

Pulp firmness

Firmness analysis was performed using an Effegi Fruit Tester texturometer (Bishop FT 327, Alfonsine, Italy) and an 8.0 mm flat tip probe. Two measurements were taken in the central region of each fruit. This parameter was expressed in Newtons (N).

Soluble Solids Content (SSC)

SSC was determined using a digital refractometer (Alpha, Atago Co., Ltd, Japan), as described by AOAC, method no. 932.12 (AOAC, 1997). Two measurements were taken per fruit, and this parameter was expressed as a percentage (%).

Hydrogen potential (pH) and titratable acidity (TA)

The Orion pH meter was used to determine the pH, with readings taken in two replicates on the pulp of the four previously separated fruits from each cultivar, which were frozen.

Titratable acidity (TA) was determined by weighing 10 g of pulp which was diluted in 50 mL of water in a 125 mL Erlenmeyer flask. This solution was then titrated with 0.1 N NaOH, with 0.1% phenolphthalein indicator until a pink color developed. TA was expressed as a percentage of citric acid per 100 g of sample.

Moisture and dry matter (DM) content

The moisture content of the fruit pulp was determined by sampling a portion of 27 mm in diameter and 10 mm in depth from the equatorial part of each fruit, after removing the epidermis (1-2 mm thick) using a potato peeler. The moisture content was determined by the loss of mass after 48 hours of drying in a forced air circulation oven at 105°C (AOAC, 1997). Dry matter (DM) was determined from the moisture percentage, where: DM (%) = 100 – moisture (%).

Chemometrics

The Unscrambler version X.3 (Camo, Oslo, Norway) was used for data analysis. The two spectra collected from each fruit (n = 32) were reduced to their mean (n = 16). Spectra were pre-processed using Standard Normal Variate (SNV), Multiplicative Scatter Correction (MSC), SNV+ De-Trend, second polynomial order of the first (d^1A) of Savitzky–Golay with smoothing window seven points (3 + 3) and nine points (4+ 4).

Principal Component Analysis (PCA) was used as the first strategy to analyze physicochemical data from eight persimmon cultivars and to perform an exploratory analysis, as it can extract important information from physicochemical data by generating principal components (PCs), which were analyzed with and without hybrid fruit with normalized data. Then PCA was also performed with the Vis-NIR spectra of persimmon fruit.

PCA was applied to the spectra to study the influence of the data in the classification of the variables and to build Partial Least Squares Discriminant Analysis (PLS-DA) models. Model performance was evaluated using the coefficient of determination of calibration (R^2_c), the root mean square error of calibration ($RMSE_C$), coefficient of determination of validation (R^2_V), the root mean square error of validation ($RMSE_V$) (Nicolaï *et al.*, 2007).

In contrast to unsupervised pattern recognition techniques, partial least squares–discriminant analysis (PLS-DA) is a supervised method designed to enhance discrimination among previously defined classes rather than to characterise overall data variability. The method projects the original variables into a reduced set of latent variables (LVs), which are orthogonal components that maximise the covariance between the predictor matrix and the response matrix associated with class membership (Wong *et al.*, 2013).

Fruit dataset was categorized into eight groups according to botanical attributes, and classification was carried out by estimating the probability of each sample belonging to a given group based on the predicted *y* values obtained from the validation set, which were modelled using Gaussian distributions, for each class, a probability density function was defined from the mean and standard deviation of the corresponding predicted *y* values, and the decision boundaries were established at the points where the probabilities of two classes intersected, allowing unknown samples to be assigned to classes according to their predicted *y* values relative to these boundaries (Tistaert *et al.*, 2011; Gad *et al.*, 2013).

Statistical analysis

The study was set up according to a completely randomized design with eight treatments (cultivars) and 4 replicates of one fruit. The physicochemical quality data were submitted to analysis of variance (ANOVA), performed using the AGROESTAT (Barbosa and Maldonado Junior, 2014) and SAS (2011).

Results and discussion

Reference analysis

Regarding fruit mass, 'Pomelo' showed higher fruit mass (156.92 g), followed by the hybrids 82 (138.27 g), 58 (129.83 g), and 158-7 (83.71 g), Table 1. According to Bertochi (1984), these hybrids were obtained by open pollination with 'Pomelo', also named 'IAC 6-22', with a 'Hanogosho' cultivar in Limeira, Brazil. Therefore, these hybrids might have inherited this genetic trait from the 'Pomelo' parent.

'Pomelo' also showed fruit with a higher length than 'Rama Forte'. All other genotypes showed similar values, including width (Table 1). It is important to mention that fruit from 'Rama Forte' had seeds, and according to Simão (1998) fruit with seeds are usually small with less mass. This information was confirmed by Curi *et al.* (2017), who reported the presence of seed as a dominant factor in determining fruit size in persimmons. However, genetic and varietal characteristics are the dominant factors in determining fruit size in persimmons (Li *et al.*, 2024).

Table 1. Dimensions of eight persimmon cultivars.

Cultivar	Mass (g)	Length (cm)	Width (cm)
Rama Forte	90.82 ± 19.52^{b}	5.49 ± 0.60^{b}	5.06 ± 0.43^{a}
Taubaté	104.91 ±7.44^{ab}	5.58 ± 0.33^{ab}	6.08 ± 0.39^{a}
Giombo	132.25 ±27.18^{ab}	5.98 ± 0.47^{ab}	6.22 ± 0.46^{a}
Pomelo	156.92 ±30.82^{a}	6.48 ± 0.45^{a}	6.59 ± 0.60^{a}
Rubi	114.21 ± 28.73^{ab}	5.95 ± 0.44^{ab}	5.44 ± 0.69^{a}
158-7	83.71 ± 18.60^{ab}	4.96 ± 0.42^{b}	5.61 ± 0.39^{a}
82	138.27 ± 25.09^{ab}	6.50 ± 0.47^{ab}	6.38 ± 0.41^{a}
58	129.83 ± 23.35^{ab}	6.00 ± 0.45^{ab}	6.18 ± 0.45^{a}

Results are reported as means ± standard deviation (S.D). $^{a\text{-}b}$ different letters indicate statistically significant differences at $p<0.05$ according to ANOVA and Tukey's post-hoc test.

These results agreed with reported by Cavalcante *et al.* (2007). Length ranged across genotypes; 'Taubaté' (6.18 cm), 'Rubi' (6.45 cm), 'Pomelo' (5.56 cm), 'Rama Forte' (4.57 cm), 'Giombo' (6.12 cm). Width was also in the range reported by Cavalcante *et al.* (2007), 'Taubaté' (5.91 cm), 'Rubi' (5.64 cm), 'Pomelo' (6.15 cm), 'Rama Forte' (5.74 cm), 'Giombo' (5.69 cm). Although the physical parameters were similar to Nascimento *et al.* (2017), it is expected variations due to a combination of factors, such as the growing environment, agronomic management, and genotype-environment interaction, which influence the expression of the morphological characteristics of persimmons.

The color of persimmon fruit revealed differences only for lightness (L*) between 'Giombo' and 'Taubaté', which are commonly grown cultivars in Brazil. 'Giombo' is a variable type and 'Taubaté' a tannic type. These cultivars showed higher L* than 'Rama Forte' (Table 2), suggesting that the fruit might possess lighter pigments or a slightly more advanced maturation stage compared to 'Rama Forte'. The L* value ranges from 0 (black) to 100 (white); therefore, higher values suggest a lighter color, which in persimmon is associated with more yellow-orange tones.

Persimmon fruit ripening is characterized by the degradation of chlorophyll and the synthesis of new pigments. This process involves modifications in the fruit color due to the presence of carotenoid compounds. As the fruit matures, the color changes from green to yellow-orange or reddish-orange, a variation directly caused by the degradation of chlorophyll and the simultaneous increase in carotenoids within the fruit's peel and pulp (Yuan *et al.*; 2006, Curi *et al.*, 2017; Bordiga *et al.*, 2019).

Conversely, the absence of significant changes in chromaticity and hue angle among persimmon cultivars at harvest might suggest that fruit were at a similar physiological stage. Similar results were found by Hasan *et al.* (2024) for chromaticity in 'Yoho' and 'Jiro' persimmon fruit. Furthermore, Nascimento *et al.*

(2017) reported that color values (L*, Hue, and Chromaticity) in 'Rama Forte', 'Giombo', and 'Pomelo' showed only slight differences, suggesting that agronomic factors may also influence this variability.

Table 2. Color of eight persimmon cultivars.

Cultivar	Lightness (L*)	a*	b*	Hue angle	Chromaticity
Rama Forte	55.30±2.02^{b}	-1.57±11.61^{a}	46.01±5.52^{a}	156.07±74.9^{a}	47.42±5.8^{a}
Taubaté	61.15±2.07^{a}	-1.70±10.63^{a}	54.13±7.97^{a}	182.93±92.4^{a}	54.97±7.5^{a}
Giombo	61.24±1.94^{a}	2.59±9.42^{a}	55.86±4.74^{a}	168.97±83.2^{a}	56.63±5.3^{a}
Pomelo	57.95±2.83^{ab}	-9.27±4.79^{a}	51.36±4.52^{a}	109.65±37.0^{a}	52.44±4.1^{a}
Rubi	56.46±2.39^{ab}	-9.00±4.84^{a}	46.83±5.77^{a}	115.49±46.2^{a}	47.95±5.5^{a}
158-7	54.33±2.61^{ab}	-9.03±6.83^{a}	40.91±4.42^{a}	115.43±40.6^{a}	42.49±3.8^{a}
82	56.18±2.67^{ab}	-12.92±2.74^{a}	48.92±5.20^{a}	105.08±4.2^{a}	50.71±4.5^{a}
58	58.46±2.53^{ab}	-10.24±3.68^{a}	52.55±4.86^{a}	101.27±4.7^{a}	53.70±4.3^{a}

Results are reported as means ± standard deviation (S.D). $^{a\text{-}b}$ different letters indicate statistically significant differences at $p<0.05$ according to ANOVA and Tukey's post-hoc test.

The physicochemical parameters can be seen in Table 3. Soluble solids content (SSC) and titratable acidity (TA) did not differ among the different cultivars, suggesting that all fruit were harvested at a similar maturity stage (Table 3). These data corroborate with Sá *et al.* (2018) and Peche *et al.* (2023) who reported similar SSC and TA for the cultivars 'Rama Forte', 'Taubaté', 'Giombo', 'Pomelo', and 'Rubi'. The SSC values ranged from 16.86% to 19.88%, and previous studies have reported values of 15.10% to 21.42% for 'Giombo' and 14.90% to 18.04% for 'Rama Forte' (Cavalcante *et al.*, 2007; Mendonça *et al.*, 2015; Sá *et al.* 2018). Murray and Valentini (1998) reported that variations in SSC are often observed in persimmons and stone fruits. These variations are attributed to a large number of associated variables, including the bioconversion of sugars, the formation of soluble molecules in the cell wall, the balance of organic acids, and the solubilization of salts.

The pH values showed a significant difference between cultivars, with lower values for the 'Rubi' and the hybrid '82'. Similar pHs were observed in 'Rama Forte' (5.59) harvested with yellow-orange skin coloration (Mendonça *et al.*, 2015). Sá *et al.* (2018) found higher values for 'Giombo' (5.90) and 'Rama Forte' (5.97) persimmons harvested when fully ripe. Thus, the similar values observed for SSC, titratable acidity (TA), and pH indicate that the fruits were at the beginning of the ripening process.

The moisture content of the fruit showed differences between cultivars, with the hybrid '82' showing higher moisture content (87.53%) than the hybrid '158-7' and the cultivars 'Rubi', 'Rama Forte', and 'Giombo' (Table 3). Similarly, the dry matter (DM) content inversely followed the moisture trend, with lower values observed in fruit of the hybrid '82' (12.47%) and differing from the forementioned genotypes (Table 3).

Table 3. Physicochemical parameters of eight persimmon cultivars.

Cultivar	SSC (%)	TA (%)	pH	Moisture (%)	DM (%)	Firmness (N)
Rama Forte	16.86±0.60[a]	0.76±0.45[a]	6.06±0.15[a]	82.25±0.90[b]	17.75±0.90[a]	16.97±2.57[a]
Taubaté	17.13±1.65[a]	1.53±0.37[a]	5.96±0.08[a]	84.49±2.26[ab]	15.51±2.26[ab]	13.67±4.12[ab]
Giombo	19.88±0.23[a]	1.13±0.26[a]	5.95±0.13[a]	82.38±0.27[b]	17.62±0.27[a]	10.13±1.25[b]
Pomelo	18.29±1.91[a]	1.40±0.22[a]	6.12±0.04[a]	85.18±1.61[ab]	14.82±1.61[ab]	16.70±2.67[a]
Rubi	17.09±2.40[a]	1.49±0.76[a]	5.04±0.07[b]	84.12±0.98[b]	15.88±0.98[a]	17.44±2.53[a]
158-7	18.71±1.96[a]	1.32±0.52[a]	6.12±0.10[a]	83.31±2.13[b]	16.69±2.13[a]	18.94±1.69[a]
82	16.91±0.46[a]	1.61±0.35[a]	5.35±0.59[b]	87.53±0.73[a]	12.47±0.73[b]	18.26±1.84[a]
58	18.16±1.07[a]	1.20±0.31[a]	6.12±0.08[a]	85.35±1.35[ab]	14.65±1.35[ab]	17.83±3.33[a]

SSC - soluble solids content, TA - titratable acidity, and DM - dry matter.

Results are reported as means ± standard deviation (S.D). [a-b] different letters indicate statistically significant differences at $p<0.05$ according to ANOVA and Tukey's post-hoc test.

The DM content is critical for fruit quality as it is related to a greater accumulation of organic compounds and the maturity stage. DM is often used to establish harvest point; thus, a higher DM indicates a riper fruit. Based on this, the fruit of hybrid '158-7', and cultivars 'Rubi', 'Rama Forte', and 'Giombo' were probably more mature than the fruits of the hybrid '82'.

Lastly, 'Giombo' fruit had the lowest firmness value (10.13 N) than the other genotypes, suggesting a softer or more mature fruit with slightly more advanced maturity stage, even though its SSC/TA values were similar (Table 3). These differences may be associated with the maturity stage differences, but also with the inherent characteristics of each cultivar, as they may have firm or soft pulp (Martins and Pereira, 1989).

Vis-NIR spectra

The average raw spectra for each persimmon cultivar obtained with a portable F-750 spectrometer is shown in Figure 1. The first absorption bands correspond to the visible wavelength region (310–750 nm), with high absorptions in the violet (380–440 nm), green (500–565 nm), and red (625–740 nm) spectral regions. corresponds to the region of photosynthetic pigments. An intense absorption band is identified near 970 nm, corresponding to the stretching overtones of the O-H bond in water. Smaller peaks and spectral overtones in the regions of 910 nm and 1000 nm also indicate the presence of sugars, resulting from the vibrations of the C-H and O-H bonds of carbohydrate molecules (Santos Neto *et al.*, 2017).

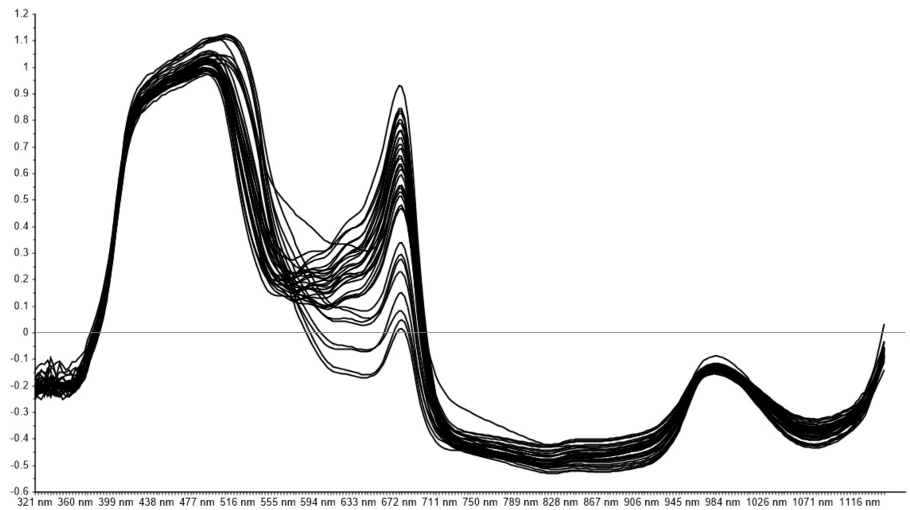

Figure 1. Vis-NIR spectra of persimmon fruit without preprocessing.

Chemometrics

Principal Component Analysis (PCA)

PCA was used to detect subtle spectral differences among persimmon cultivars, a technique that facilitates identification of potential groupings among samples based on their underlying similarities (Cozzolino *et al.*, 2011). The exploratory analysis using PCAs revealed distinct patterns across the different genotypes. In Figure 2, it is observed that there is a wide dispersion of data, especially due to the presence of hybrids (158-7, 82, and 58), which exhibit high genetic variability.

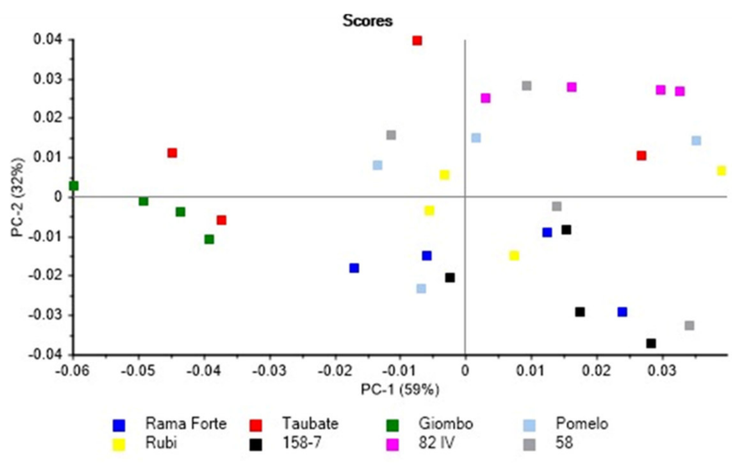

Figure 2. Principal component analysis (PCA). PC1 and PC2 scores obtained from normalized physicochemical data of persimmon fruit.

The separation becomes more evident, allowing the identification of grouping trends based on the intrinsic characteristics of each cultivar, Figure 3. The PCA loadings indicate that PC1 is positively correlated with firmness, whereas PC2 is mainly defined by moisture content, allowing for a better separation of the cultivar, Figure 3.

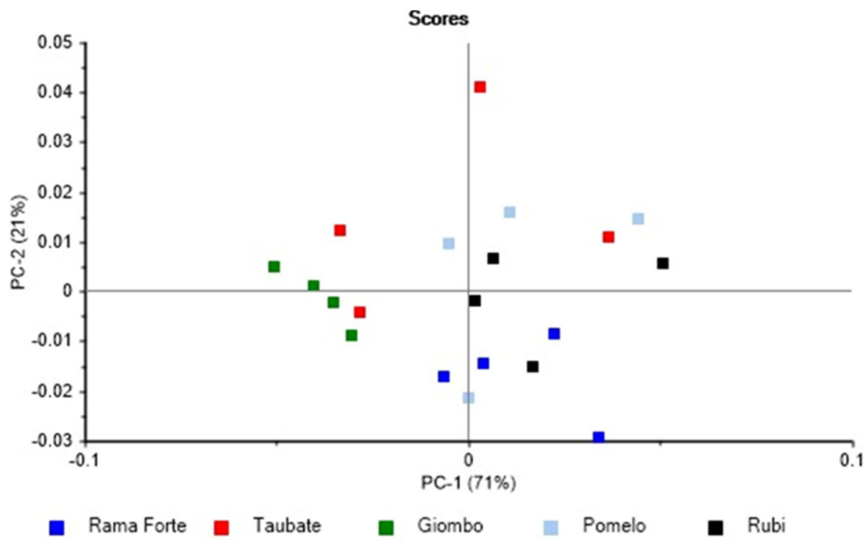

Figure 3. Principal component analysis (PCA). PC1 and PC2 scores obtained from the normalized physicochemical data of persimmon fruit without hybrids.

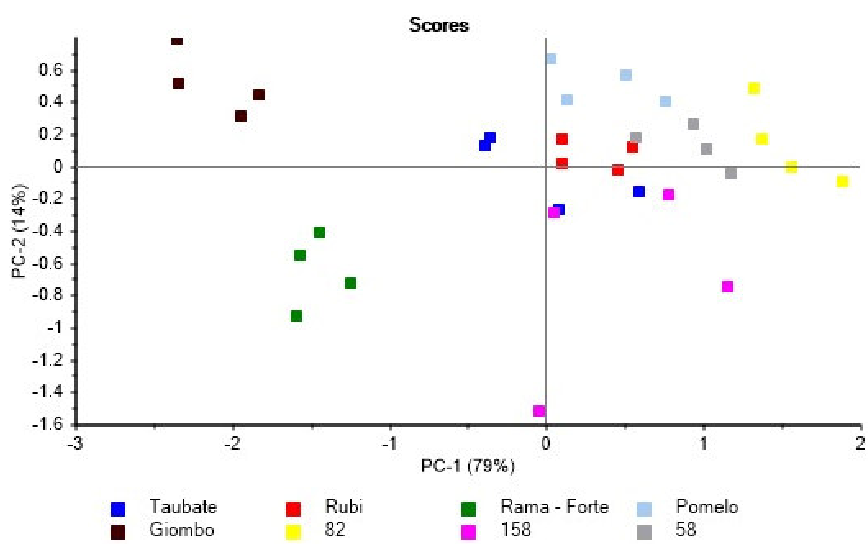

Figure 4. Principal component analysis (PCA). PC1 and PC2 scores obtained from raw spectra data of persimmon fruit.

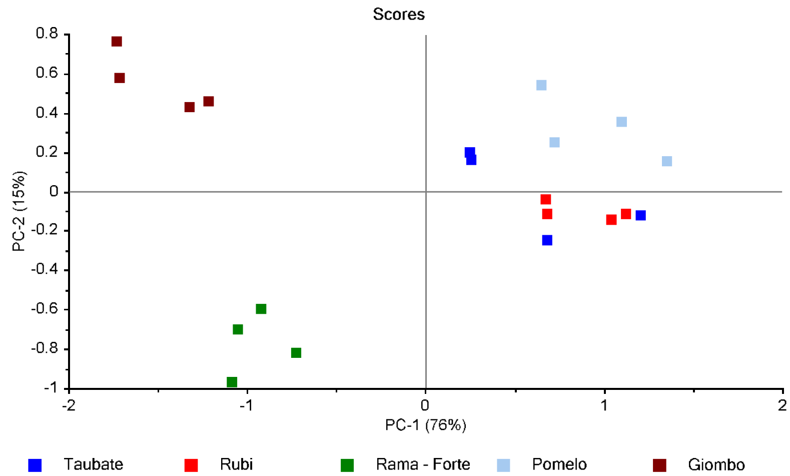

Figure 5. Principal component analysis (PCA). PC1 and PC2 scores obtained from raw spectra data of persimmon fruit without hybrids.

Figure 4 shows better performance of the aggregation using raw spectra with 79% PC, followed by the construction of a new PCA with raw spectra and without hybrids, as shown in Figure 5. Although fruit from the hybrids '158-7', '82', and '58' were initially included, they did not perform well due to their genetic variability and were subsequently excluded, as observed in Figure 5.

In Figure 4, the scores of the first two principal components (PCs) explained 93% of the data variance using the raw Vis-NIR spectra and an improved 99% of the explained variance when the spectra were pre-processed with standard normal variate (SNV) (Figure 6). Zhang *et al.* (2011) successfully used the first two principal components (PCs) to explain 95.51% of the total variance when analyzing the NIR spectra of three types of persimmon cultivars, 'covered persimmon', 'Cynanchum persimmon', and 'red persimmon'.

'Rama Forte' and 'Giombo' fruit concentrated on the left side of PC1, while the other fruit from the other genotypes on the right side (Figure 5 and 6). This separation is noteworthy because 'Rama Forte' and 'Giombo' belong to the variable group, pulp characteristics depend on seed presence. In contrast, 'Taubaté', 'Rubi', and 'Pomelo' belong to the tannic group (Martins and Pereira, 1989). Thus, the PCA suggested a tendency to cluster formation according to these fundamental characteristics.

Following this exploratory step and appropriate spectral pre-treatments, partial least squares discriminant analysis (PLS-DA) was applied to classify the 'Rama Forte' and 'Giombo' cultivars, which exhibited the most discernible trends in the PCA scores.

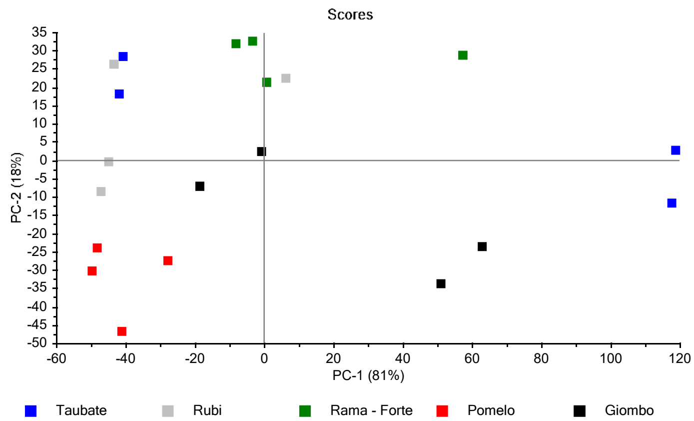

Figure 6. PC1 and PC2 scores obtained from Vis-NIR spectra of persimmon fruit preprocessed with SNV without hybrids

Partial Least Squares Discriminant Analysis (PLS-DA)

Adequate classification was observed exclusively for the 'Rama Forte' and 'Giombo' cultivars (Table 4), since, as shown in Figures 4 and 5, these cultivars exhibited the clearest separation from the others. For the 'Rama Forte', the optimal classification was achieved using Vis-NIR spectra pre-processed with the 2nd derivative of Savitzky-Golay (4+4) + SNV, yielding a coefficient of determination for calibration (R^2_C) of 0.98 and a coefficient of determination for validation (R^2_V) of 0.75.

For the 'Giombo' cultivar, the best results were obtained applying the pre-processed Vis-NIR spectra with the 1st derivative of Savitzky-Golay (3+3) + MSC, yielding a R^2_C of 0.93 and R^2_V of 0.68 (Table 4).

Although these results demonstrate the feasibility of distinguishing these two cultivars, the moderate validation accuracy (R^2_V 0.75 and 0.68) suggests the need for a larger, more diverse dataset with more variability.

PLS-DA was also used as discriminant tool by Munera *et al.* (2021). These authors used VIS/NIR hyperspectral imaging to detect damage stages in 'Rojo Brillante' persimmon and achieved a total accuracy of 99.4%. Furthermore, the capacity of spectroscopy to evaluate postharvest quality, including attributes like soluble tannins (Amorim *et al.*, 2024) and moisture (Chen *et al.*, 2022), is crucial for identifying favorable crop characteristics, providing robust indicators for selecting superior genetic material for the consumer market (Menezes *et al.*, 2022).

Table 4. Performance of calibration and validation steps of partial least squares discriminant analysis (PLS-DA) models for the classification of the cultivars 'Rama Forte' and 'Giombo' with different pre-processing and variable selection.

Cultivar	Preprocessing	Variable Selection	Calibration $RMSE_C$	Calibration R^2_C	Validation $RMSE_V$	Validation R^2_V
Rama Forte	None	250	0.21	0.72	0.29	0.52
Rama Forte	SNV (Standard Normal Variate)	250	0.17	0.80	0.29	0.53
Rama Forte	2nd derivative Savitzky–Golay (4+4)	114	0.04	0.98	0.30	0.54
Rama Forte	2nd derivative Savitzky–Golay (4+4) + SNV	96	0.08	0.96	0.21	0.75
Giombo	None	250	0.24	0.64	0.30	0.48
Giombo	SNV (Standard Normal Variate)	250	0.23	0.65	0.32	0.48
Giombo	1st derivative Savitzky–Golay (3+3) + MSC	187	0.11	0.93	0.27	0.60
Giombo	1st derivative Savitzky–Golay (3+3) + MSC	146	0.10	0.93	0.25	0.68

Note: $RMSE_C$ = Root Mean Square Error of Calibration; R^2_C = Coefficient of Determination (calibration); $RMSE_V$ = Root Mean Square Error of Validation; R^2_V = Coefficient of Determination (validation); SNV = Standard Normal Variate; MSC = Multiplicative Scatter Correction.

The graphical representation of the best-performing models is illustrated by the dispersion of values for the respective classes in Figures 7 and 8 for the 'Rama Forte' and 'Giombo', respectively. The results confirm that Vis-NIR spectroscopy can be successfully used for the classification of intact fruit of at least these two persimmon cultivars. However, the validation coefficients suggest that further information needs to be integrated into the models to reduce the root mean square error and significantly improve their robustness. Specifically, achieving enhanced model performance and generalizability requires addressing the need for additional sample variability and the implementation of more rigorous chemometric model construction conditions.

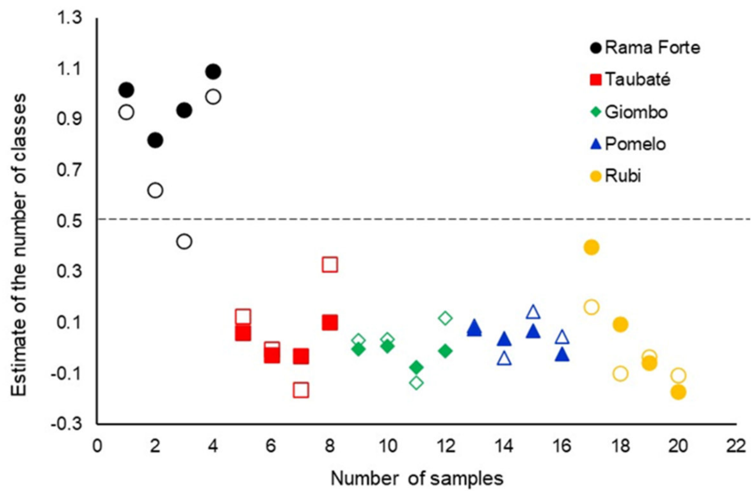

Figure 7. Dispersion of calibration samples (full symbols) and validation (empty symbols) for discrimination of the cultivar 'Rama Forte' by PLS-DA.

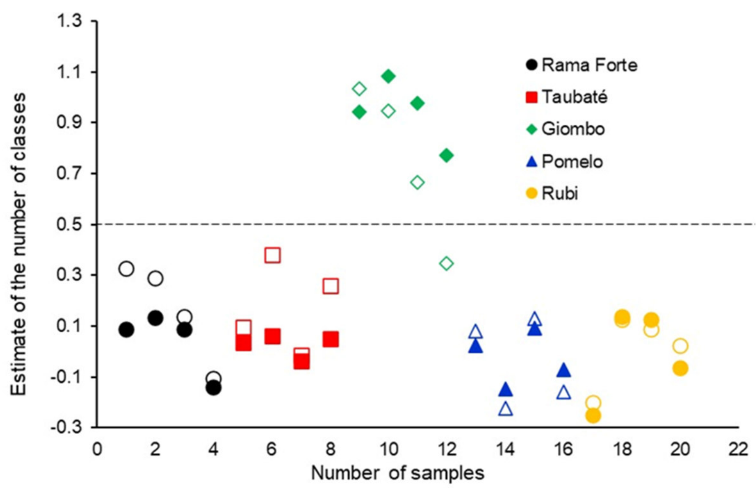

Figure 8. Dispersion of calibration samples (full symbols) and validation (empty symbols) for discrimination of the cultivar 'Giombo' by PLS-DA.

Conclusions

The physicochemical quality was similar in all evaluated genotypes. However, 'Pomelo' fruit and its hybrids exhibited the higher fruit mass and diameter. Taubaté and Giombo showed higher lightness (L*), and hybrid 82 was distinct with the lowest pH, the highest moisture content, and, consequently, the lowest dry matter. Furthermore, the Giombo cultivar recorded the lowest firmness value.

Classification models using Vis-NIR spectra and PLS-DA were developed and allowed adequate classification of Rama Forte ($RMSE_C$ of 0.08%, R^2_C of 0.96, $RMSE_V$ of 0.21%, and R^2_V of 0.75) and Giombo ($RMSE_C$ of 0.10%, R^2_C of 0.93, $RMSE_V$ of 0.25%, and R^2_V of 0.68) fruit. These results underscore that Vis-NIR spectroscopy and PLS-DA can be used for rapid and nondestructive varietal discrimination of these two persimmon cultivars, thereby guaranteeing the authenticity of the product offered to consumers. However, to significantly improve model robustness, reduce the root mean square error, and ensure broader applicability across other cultivars, further research is required. This future study should focus on expanding the sample population to capture greater genetic and environmental variability and evaluate additional postharvest conditions to better define quality indicators.

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