Eur. J. Hortic. Sci. | ISSN 1611-4426 print, 1611-4434 online | https://doi.org/10.17660/eJHS.2022/039 | © ISHS 2022

Original article

Morphological, qualitative, and nutraceutical differences between fruits of *Actinidia deliciosa* (A. Chev.) C.F. Liang & A.R. Ferguson and *A. chinensis* Planch varieties

G. Gullo[1], A. Dattola[1], V. Vonella[1], A. Allegra[2] and R. Zappia[1]

[1] Department of Agraria, Mediterranean University of Reggio Calabria, Reggio Calabria, Italy

[2] Department of Agriculture, Food and Forestry Sciences, University of Palermo, Palermo, Italy

Summary

Background – **The green-fleshed 'Hayward' cultivar has dominated the Italian kiwi market. Economic interest in yellow-fleshed kiwifruit cultivars belonging to *Actinidia deliciosa* species has increased of late.** *Objectives* – **Kiwifruit quality depends on several factors, including the growing environment. This study aimed to evaluate the qualitative and nutraceutical content of fruits of three *Actinidia chinensis* Planch cultivars and *A. deliciosa* (A. Chev.) C.F. Liang & A.R. Ferguson, 'Hayward' cultivar.** *Methods* – **The trial was conducted during two production seasons (2019 and 2020) on a farm located in southern Italy. 'Hayward' (HY), 'Jintao' (JT), 'Gold3' (G3), and 'Donghong' (DH) trees were planted in spring 2015. At harvest, fruit biometric parameters, ripening indices, and nutritional parameters were recorded. All data were subjected to analysis of variance and PCA.** *Results and discussion* – **The cultivars 'Gold3' and 'Jintao' had higher carpometric and quality values than 'Hayward' kiwifruit, especially in fresh weight, total soluble solids, flesh firmness, total polyphenols, ascorbic acid, and total antioxidant capacity. 'Donghong' significantly differed from the other cultivars in terms of the TSS/TA ratio, total polyphenols, and total flavonoids.** *Conclusion* – **The four cultivars significantly differed in quality parameters in the environment in which the experiment was conducted, with the yellow-fleshed cultivars exhibiting superior quality.**

Keywords

total polyphenols, total antioxidant capacity, ascorbic acid, kiwifruit

Significance of this study

What is already known on this subject?

- *A. chinensis* cultivars have a better budbreak than *A. deliciosa* in environments with low cold requirements.

What are the new findings?

- One of these cultivars is characterised by yellow flesh with a red endocarp; this cultivar is designated as red-fleshed.

What is the expected impact on horticulture?

- Flesh richer in nutraceutical components may change the kiwi market.

Introduction

The species of *A. chinensis* described by Planchon (1847), were divided by Liang (1975) into two varieties: *A. chinensis* var. *chinensis*, and *A. chinensis* var. *hispida*. The latter variety had also been described by Chevalier, first as *A. latifolia* var. *deliciosa* (1940) and then as *A. chinensis* var. *deliciosa* (1941). The differences between *A. chinensis* var. *chinensis* and *A. chinensis* var. *deliciosa* (vegetation, flower, fruit morphology, and chromosome number) led to the finding that they should be considered as two distinct species (Liang, 1975; Gui, 1981; Zhu, 1983). Therefore, Liang and Ferguson (1984) proposed that *A. chinensis* var. *deliciosa* should be considered as a distinct species under the name *A. deliciosa.*

Kiwifruit is currently cultivated in temperate areas with latitudes between 25° and 45°. China, Italy, New Zealand, Chile, and Greece are the top five kiwi fruit producers, accounting for 87% of global production (Zhang et al., 2020a). Italy ranks second in kiwi production worldwide, with 316,443 tons produced in 2019 (Balestra and Costa, 2020; Zhang et al., 2020b).

A few decades ago, the Italian kiwi market was dominated by the green-fleshed 'Hayward' cultivar, belonging to *A. deliciosa* (A. Chev.) C.F. Liang & A.R. Ferguson. However, the area invested in yellow-fleshed varieties has increased in the last decade. Out of a total of 24,859 ha, green kiwi occupies 19,859 ha (79.89%) with 257,295 tons (81.3% of the total production), and yellow kiwi occupies 5,000 ha (20.11%) with 59,148 tons (18.7% of the total Italian kiwifruit production) (Balestra and Costa, 2020). Among the main green kiwi cultivars are three *A. chinensis* Planch cultivars, namely 'Jintao', 'Gold3', and 'Donghong'. 'Jintao' is a yellow-fleshed tetraploid genotype ($2n = 4x = 116$) (Huang et al., 2002), bred at the Wuhan Institute of Botany (WIB). It has a low cooling demand (approximately 350–450 h), making it well adapted to a Mediterranean climate with mild winters and producing high-quality fruit. It was released to European kiwifruit growers in 2001 (Cipriani and Testolin, 2007) and is widely preferred for its productivity, good fruit quality, and shelf life.

'Gold3' or 'G3', also known as 'Zesy002', has replaced 'Hort16A' because of its increased tolerance to bacterial kiwi cancer caused by *Pseudomonas syringae* (Scortichini, 2017; Cozzolino et al., 2020). 'G3' has light yellow flesh with a greenish ring, sweet flavour, and a 3–4 month shelf life. 'Donghong' is a new cultivar widely cultivated in the Chinese provinces of Hubei and Sichuan (Cozzolino et al., 2020; Nie et al., 2020).

Kiwifruit plays an important role in human health because it is a source of several macro- and micronutrients, such as proteins, lipids, carbohydrates, vitamins, minerals, and organic acids (Singletary, 2012; Henare, 2016; Cozzolino et al., 2020; Dias et al., 2020). In addition, several phytochemicals, including phenolic acids, flavonoids, carotenoids, and chlorophylls, have been identified in yellow- and green-fleshed kiwi cultivars (McGhie, 2013).

Kiwifruit flavour is related to its aroma, taste (sugars and acids), and texture (Henare, 2016). However, fruit quality depends on many factors, including the cultivation environment (Di Vittori et al., 2018).

This study aimed to evaluate the qualitative and nutraceutical content of three *Actinidia chinensis* cultivars and compare them with those of 'Hayward' kiwifruit (*Actinidia deliciosa*).

Materials and methods

Orchard

The experiment was carried out during two production seasons (2019 and 2020) in Gioia Tauro Plain (RC), Calabria, Southern Italy (38°30'32.6"N, 15°58'31.3"E). The 'Hayward' (HY), 'Jintao' (JT), 'Gold3' (G3), and 'Donghong' (DH) trees had been planted in the spring of 2015 on farms close to each other (HY and G3 in the same farm), in sandy soil, with pH 6.7 (±0.29; Sub-acid), 2.4% (±0.3) organic matter, and 1.6 g kg^{-1} (±0.2) nitrogen content. The vines were spaced at 5 × 2.5 m apart (800 vines ha^{-1}), and a north-to-south row orientation was adopted. 'Belén' cultivar trees were used as pollinators for the JT, G3, and DH cultivars at a male/female ratio of 1:6. Additionally, the 'Toumuri' cultivar tree was used as a pollinator for the HY cultivar at a male/female ratio of 1:8.

The trees were trained using a pergola system under net. The yearly winter pruning (December) was combined with summer pruning (July).

The orchards were managed with standard pruning, irrigation, and fertilisation operations recommended for each cultivar.

Treatment and experimental design

An experimental design was adopted with three row segments of six plants, randomly selected per orchard, then 18 trees per cultivar.

1. Measurements.

Number of buds. – After winter pruning, number of buds per tree was determined from the six plants per cultivar, and the number of buds per hectare was calculated.

Fruit biometric parameters. – Fruits were collected and analysed using the BBCH-scale (Biologische Bundesanstalt, Bundessortenamt, and CHemische Industrie) (phenological stage 85) for plant phenological stages according to Zadoks et al. (1974).

The production per tree (fruit number and weight per tree) was determined at harvest on 24 September 2019 and 26 September 2020 for DH; 8 October 2019 and 9 October 2020 for JT; 11 October 2019 and 10 October 2020 for G3; 14 November 2019 and 17 November 2020 for HY. The number of fruits per hectare was calculated. At harvest, six fruits were randomly collected from the canopy of the six vines per cultivar (treatment) (6 fruits × 6 trees × 3 rows = 108 fruits). The longitudinal (H) and transversal [minimum transversal diameter (DT_m) and maximum transversal diameter (DT_M)] diameters were immediately determined using a precision calliper. Fresh weight (FW) was measured using an electronic balance (Mettler-Toledo, Greifensee, Switzerland). At the same time, flesh firmness (FF) was determined from the equatorial zone of the fruit, on two opposite sides using a PCE 100 digital penetrometer with an 8-mm probe (PCE Italia s.r.l., Capannori, Italy). Pulp colour was measured using a Minolta spectrophotometer CM-700d (Minolta, Inc., Tokyo, Japan) in terms of CIELAB and HSB colour spaces; pulp colour was also observed during the fruit's early development stage [BBCH-scale (phenological stage 71)]. The transversal diameter mean ($DT = DT_M/DT_m$) and relative fruit length (H/DT ratios) were calculated.

Maturation indexes. – Total soluble solids content (TSS) as Brix was measured using a digital refractometer (PAL-1; Atago, Tokyo, Japan) in juice drops obtained by squeezing the apex and base of each fruit. Titratable acidity (TA) was determined by titrating 10 mL of the juice diluted with distilled water (1:1) with 0.1 N NaOH to pH 8.2; titration results were expressed as citric acid %.

Dry matter content (DM) was determined by extracting a horizontal slice of fruit tissue from the equatorial zone of each fruit. The slice thickness was approximately 1 cm, and fresh weight (FW) was recorded. The slice was placed in a dehydrator at 70°C until a constant dry weight was reached. DM was expressed as a percentage of FW.

Nutraceutical parameters. – The ascorbic acid (AA) content was determined using a procedure based on reducing the 2.6-dichlorophenol-indophenol dye using ascorbic acid (mg ascorbic acid 100 g^{-1} FW).

Total polyphenol content (TPC) and total antioxidant capacity (TAC) analyses were performed. For each block, five fruit for the graft combination were placed in polyethene bags and frozen at -80°C until nutraceutical analysis. Kiwifruit was defrosted, and 5 g of kiwifruit pulp was placed in a 100 mL mixture of methanol, distilled water, and acetic acid (80:19:1; v:v:v) and homogenised using an Ultraturrax blender at 20,000 rpm (T 25 Basic; IKA Werke GmbH & Co. KG, Staufen, Germany). The extract was used to detect TPC and TAC.

The TPC (mg gallic acid equivalents g^{-1} FW) was determined using the Folin-Ciocalteu method (Slinkard et al., 1997). TAC was determined using the modified TEAC assay and expressed as µmol Trolox equivalents g^{-1} FW (Pellegrini et al., 1999; Re et al., 1999; Scalzo et al., 2005) TPC and TAC were analysed separately using a Lambda 35 spectrophotometer (PerkinElmer, Waltham, MA, U.S.A.). Before measuring the TPC and TAC, standard curves were prepared for each test.

The total flavonoid content (TFD) of the samples was measured using a colourimetric method (Zhishen et al., 1999; Dewanto et al., 2002). The methanolic extract (250 µL) was mixed with 1.25 mL of DI water and 75 µL of 5% $NaNO_2$ solution and then allowed to mix for 6 min. After adding 150 µL of 10% $AlCl_3$ solution and mixing for 5 min, the reaction was initiated by adding 0.5 mL of 1 M NaOH, and the total volume was made up to 2.5 mL with DI water. Sample absorbance was read at 510 nm using a UV/Vis spectrophotometer (Lambda 35, PerkinElmer). Total flavonoid content was expressed as µg (+)-catechin equivalents (CA) g^{-1} FW.

The preparation of samples for total flavonol content (TFL) was done according to the aluminium chloride colourimetric technique. Briefly, 0.5 mL of each extract was mixed with 0.5 mL aluminium chloride (2%), and then 1.5 mL potassium acetate (5%) was added. After 150 min, absorbance was measured at 440 nm. The calibration curve was plot-

ted using different concentrations of quercetin equivalents (Miliauskas et al., 2004).

Total Chl (*a*+*b*) (TChl) and carotenoids (TCar) were calculated according to the method described in Porra et al. (1989).

TChl and TCar of pulp from each cultivar were extracted using 80% acetone and centrifuged at 20,000 rpm for 20 min at 4°C. All pigment extraction was performed in the dark with the samples kept on ice. The absorbance of the supernatant was measured using a dual-wavelength/double-beam spectrophotometer (Lambda 35, PerkinElmer). The equations used for the quantification of chlorophyll *a*, chlorophyll *b*, and carotenoids are as follows:

$$\text{Chl } a \text{ } (\mu g \text{ } mL^{-1}) = (12.25 \times A\ 663.2) - (2.79 \times A\ 648.8);$$

$$\text{Chl } b \text{ } (\mu g \text{ } mL^{-1}) = (21.50 \times A\ 648.8) - (5.10 \times A\ 663.2);$$

$$\text{Total Chl } (\mu g \text{ } mL^{-1}) = (17.67 \times A\ 648.8) + (7.12 \times A\ 663.2);$$

$$\text{Carotenoids } (\mu g \text{ } mL^{-1}) = [(1{,}000 \times A\ 470) - (1.82 \times \text{Chl } a) - (85.02 \times \text{Chl } b)]/198.$$

All data were subjected to ANOVA, and the means were compared using Tukey's test when the ANOVA indicated significant ($P<0.05$) variable effects. All data are reported as means for both years. All data analyses were performed using IBM SPSS Statistics, v. 22 (SPSS Inc., Chicago, IL, U.S.A.).

The variables were also used in a principal component analysis (PCA) to evaluate more complex relationships between parameters and identify how they were related to the southern Italian environment. The square cosine was calculated because it shows the importance of a factor (principal component) for a given observation; it corresponds to the square of the cosine of the angle from the right triangle made from the origin, the observation, and its projection on the component. All data analyses were performed using XLstat, v. 2014.5.03 (Addinsoft SARL, New York, NY, U.S.A.).

Table 1. Fruit and bud number of three *Actinidia chinensis* cultivars ('Jintao', 'Gold3', and 'Donghong') and one *Actinidia deliciosa* cultivar ('Hayward').

Cultivar	Fruits number (no. tree^{-1})	Buds number (no. ha^{-1})
Donghong	480.67 ± 28.89 ns	220.000b ± 288.9
Gold3	548.00 ± 22.38 ns	220.000b ± 238.5
Jintao	453.20 ± 36.98 ns	220.000b ± 210.9
Hayward	555.33 ± 37.51 ns	250.000a ± 177.5

Results and discussion

Fruit production per tree was not significantly different among the cultivars (Table 1). HY is a cultivar with a higher requirement for cold units than the other cultivars (Inglese and Gullo, 1992). This often represents a limitation in the area where experiments can be conducted. This often represents a limitation in the area where experiments can be conducted. Therefore, a higher load of buds per plant were left in the HY cultivar compared to other cultivars during the winter pruned to overcome this limitation, as observed by other authors (Inglese et al., 1998; Gullo et al., 2013) (Table 1).

The green-fleshed (HY) cultivar developed slower than the other cultivars in the present study; HY's flowering stage was recorded during the last days of May (29 May 2019; 30 May 2020), whereas the phenological stage BBCH 85 (harvest maturity stage) of HY cultivar was reached 169 (2019) and 171 (2020) days after flowers bloom (DAFB; during the second ten days of November) (Table 2). Compared with the other cultivars, HY was harvested +61 (2019)/+62 (2020), +34 (2019)/+38 (2020), and +37 (2019)/+39 (2020) days later than DH, G3, and JT, respectively, in agreement with the observations of other authors (Huang et al., 2002).

DH flowering was detected during the first ten days of May (9 May 2019 and 10 May 2020). DH fruit reached the BBCH 85 phenological stage during the last days of September, at 138 (2019) and 139 (2020) DAFB; the fresh weight of its fruit was 15% lower than that of HY (Table 2) but was similar to that reported by other authors for the same cultivar (Nie et al., 2020).

The G3 flowering stage was recorded during the second ten days of May (17 May 2019 and 20 May 2019). The fruit of the G3 cultivar reached the harvest maturity stage in the first ten days of October (Table 1), at 144 DAFB in both years, with a fresh fruit weight (FFW) 11% higher than that of HY (Table 3). However, this value was lower than the value reported for a U.S. patent, licensed on behalf of Zespri Group Ltd. (Te Puke, New Zealand), according to which the average weight of the fruit is approximately 136 g (U.S. patent 22.355 P3; Table 3).

The FFW of JT was 8% higher than of HY fruit and surpassed the 100 g weight with which the variety was licensed (Hopping, 1990). Finally, JT flowering was detected during the second ten days of May; its fruit was harvested in the first ten days of October, at 154 (2019) and 151 (2020) DAFB, earlier than found for the same cultivar in another area of Gioia Tauro Plain, but other years (Gullo et al., 2020).

In kiwi trees, similar to pear and apple trees, flowers are grouped in inflorescences botanically defined as "racemus",

Table 2. Flowering and harvest times of the three *A. chinensis* cultivars ['Jintao' (JT), 'Gold3' (G3), and 'Donghong' (DH)] and one *A. deliciosa* cultivar ['Hayward' (HY)]. The harvest time is expressed in Julian days and days after flowers bloom (DAFB).

Cultivar	Year	Flowering time	Harvest time (date)
HY	2019	29/05	14/11 (169 DAFB)
HY	2020	30/05	17/11 (170 DAFB)
DH	2019	09/05	24/09 (138 DAFB)
DH	2020	10/05	26/09 (139 DAFB)
G3	2019	17/05	8/10 (153 DAFB)
G3	2020	20/05	10/10 (153 DAFB)
JT	2019	11/05	18/10 (164 DAFB)
JT	2020	11/05	19/10 (161 DAFB)

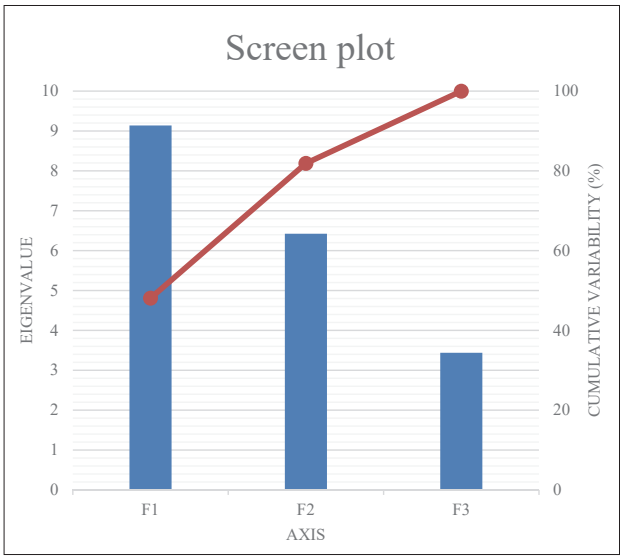

Figure 1. Screen plot of the eigenvalues and cumulative variability of the three components generated and based on the PCA of the carpometric and qualitative variables measured for the four observations.

with a central flower (Antognozzi et al., 1996). In our experiment, only the central fruit remained during thinning in all cultivars. In the G3 cultivar, the average FFW and some fruit proprieties (dry matter, flesh firmness, and colour intensity) are affected by the type of flower from which the fruit originates (terminal or lateral), as reported by Richardson et al. (2019). These authors reported that fruit developed from terminal flowers with early opening showed an increase in weight of 12–13 g compared with fruit from the other flowers and had better qualitative properties. However, other authors (Jordan et al., 1997) did not observe differences between the racemus flowers of the HY cultivar.

Relative fruit length was significantly greater in the fruit of JT followed by DH, G3, and HY; therefore, the fruit of JT had the most elongated shape, whereas HY showed a more flattened shape (Table 3). According to current norms, fruits of cultivars derived from *A. chinensis* and *A. deliciosa*, must have a minimum diameter/maximum diameter ratio not lower than 0.8 to be included in the "extra" category. At harvest, all cultivars exceeded the threshold value. However, this value was significantly higher in the JT and G3 cultivars; therefore, their section fruit was more circular. The ratio was lowest in HY; therefore, its fruit section was flat (Table 3).

In Actinidia trees, carbohydrate competition between different plant organs causes variations in the fruit's weight and composition. Dry matter content (DM) and total soluble solids (TSS) are thought to be important ripening indices for defining the optimal harvest time in kiwifruit (Mitchell et al., 1992). The DM is constant during the ripening phase, albeit the small net losses due to the respiration process (Beever and Hopkirk, 1990). Carbohydrates accumulate in large quantities during fruit development approximately 75% of the total DM (Burdon et al., 2004). These are transformed into simple sugars. Thus, the DM indicates the level of potential or actual sugars in the fruit.

According to some authors (Prudent et al., 2009), a DM of >15% ensures palatable fruits for consumers at maturity. In the DH and JT cultivars, the DM value was 2%, which was significantly higher than that of HY (Table 4). The lowest DM was recorded in HY cultivar (18.41 ± 8.34); however, it was above the average range (14–17%), which HY generally reaches at harvest (Beever and Hopkirk, 1990).

The DM reported in the G3 cultivar was significantly higher than that in the other cultivars; its value was 4% higher than that of HY (Table 4). Some authors have shown that DM and TSS decreased as average fruit weight increased (Brady, 1987; Nardozza et al., 2010); an opposite tendency was observed for the G3 cultivar where smaller-sized fruit accumulated lower DM (Richardson et al., 2019).

The highest titratable acidity value was reported for HY fruit (7.34 ± 0.35%). Titratable acidity values for the G3, JT, and DH fruit were 10, 32, and 34% lower, respectively, than that of HY (Table 4).

An opposite trend was observed for the TSS/TA ratio. The lowest values were observed for the HY cultivar (1.01 ± 0.04), whereas the highest ratio was observed in JT fruit (92% higher than cultivar HY; Table 4). In G3 and DH fruit, the TSS/TA ratio was 52% higher than that of the HY fruit (Table 4).

In JT and G3 fruit, firmness at harvest was similar but 13% higher than in HY fruit. In contrast, DH fruit had the lowest pulp firmness, which was 13% lower than in HY fruit.

In all four cultivars, kiwifruit showed green colouration during the early stages of development (BBCH- phenological stage 71). Later, the pulp undergoes drastic changes in chemical composition and ultrastructure, associated with tissue softening and carbohydrate and organic acid metabolism changes. Chloroplasts are converted into chromoplasts with a concomitant loss of chlorophyll, often accompanied by the accumulation of carotenoids such as lutein and β-carotene (Moser and Matile, 1997). These changes are in many ways similar to those undergone by leaves when they turn yellow during senescence (Borovsky and Paran, 2008). This process is triggered by the dismantling of photosynthetic chlorophyll-protein complexes, mediated by a protein localised in chloroplasts called stay-green (SGR). Unlike the fruit of yellow-fleshed cultivars, HY kiwifruit seems to maintain a green pulp pigmentation until ripening due to insufficient activity of the enzymes involved in chlorophyll degradation processes and a greater "tightness" of chloroplasts.

Table 3. Carpometric parameters of the three *A. chinensis* cultivars ('Jintao', 'Gold3', and 'Donghong') and one *A. deliciosa* cultivar ('Hayward').

Cultivar	Fresh weight (g) ± SE	Longitudinal diameter (mm) ± SE	Transversal diameter (mm) ± SE	DTm/DTM ± SE	H/DT ± SE
Donghong	92.21c ± 2.46	67.36c ± 0.84	48.75c ± 0.58	0.895b ± 0.011	1.38b ± 0.02
Gold3	121.73a ± 2.42	70.57a ± 0.53	49.82b ± 0.33	0.911a ± 0.007	1.35b ± 0.03c
Jintao	109.73b ± 4.02	64.40b ± 1.34	53.86a ± 0.61	0.848c ± 0.021	1.19c ± 0.02
Hayward	117.1a ± 2.30	70.53a ± 2.81	49.93b ± 0.38	0.943a ± 0.009	1.41a ± 0.01

Different letters indicate significant differences ($P \leq 0.05$) between cultivars; n.s.: not significant.

Table 4. Fruit maturation indices [dry matter content (DM); flesh firmness (FF); total soluble solids (TSS); titratable acidity (TA); and TSS/TA ratio] of the three *A. chinensis* cultivars ('Jintao', 'Gold3', and 'Donghong'), and one *A. deliciosa* cultivar ('Hayward').

Cultivar	DM (%)	FF (kg cm^{-2})	TSS (°Brix)	TA (%)	TSS/TA
Donghong	20.54b ± 0.41	7.07c ± 0.29	8.33b ± 0.44	4.94c ± 0.16	1.69b ± 0.15
Gold3	22.21a ± 0.23	9.49a ± 0.31	10.13a ± 0.32	5.80b ± 0.19	1.75b ± 0.07
Jintao	19.27b ± 0.47	9.07a ± 0.35	9.85a ± 0.45	4.90c ± 0.25	2.01a ± 0.13
Hayward	18.41c ± 0.91	8.35b ± 0.40	7.42c ± 0.42	7.34a ± 0.35	1.01c ± 0.04

Different letters indicate significant differences ($P \leq 0.05$) between cultivars; n.s.: not significant.

Table 5. Fruit colourimetric parameters of the three *A. chinensis* cultivars ('Jintao', 'Gold3', and 'Donghong') and one *A. deliciosa* cultivar ('Hayward').

Cultivar	*L**	*a**	*b**	Chroma	°Hue
Donghong	68.59a ± 0.5	-2.53a ± 0.3	23.87a ± 0.4	24.13a ± 0.4	97.10a ± 0.5
Gold3	72.96a ± 0.3	-2.71a ± 0.3	20.95b ± 0.4	21.26b ± 0.4	100.58b ± 2.3
Jintao	66.04b ± 1.2	0.32b ± 0.3	23.10a ± 1.1	23.16a ± 1.1	93.72a ± 0.4
Hayward	64.65b ± 0.5	-5.68c ± 0.1	23.48a ± 0.3	24.19a ± 0.4	103.32b ± 0.2

Different letters indicate significant differences ($P \leq 0.05$) between cultivars; n.s: not significant.

Among the different chromaticity coordinates, the most important in *Actinidia* cultivars is the hue degree, especially in yellow-fleshed fruit. In the JT cultivar, the hue angle below which the product should be harvested is 104° (Chiabrando and Giacalone, 2012), whereas, in the G3 cultivar, it is 103° (U.S. patent 22.355 P3). In the present study, both JT that G3 reached hue angle values well below those prescribed at 93.72°±0.4 and 100.58°±2.3 at harvest, respectively (Table 5).

In DH kiwifruit, the hue angle detected was 95.75°±0.75 upon reaching the ripening stage. It is evident that the HY cultivar showed the highest hue angle values being a green-fleshed variety (103.32°±0.2) (Table 5).

Phytochemical content is influenced by factors such as ripeness, cultivation techniques, soil and climatic environment, storage conditions, and genotype (Lee and Kader, 2000).

In the present study, we observed that ascorbic acid (AA) content of *A. chinensis* was significantly higher, approximately two-fold, than in fruit of green-fleshed cultivars (Table 6), consistent with Lee and Kader (2000). Indeed, they demonstrated that AA content in kiwifruit samples from *A. chinensis* genotypes was higher than the average content of the *A. deliciosa* HY cultivar. These results suggest that, as reported by Tavarini et al. (2008) in kiwifruits, vitamin C contributed to antioxidant capacity much more than other antioxidant constituents, such as phenols or carotenoids. In contrast, in other fruits, the greatest contribution of antioxidants is from polyphenols (Gallotta et al., 2018) or citric acid (Allegra et al., 2018).

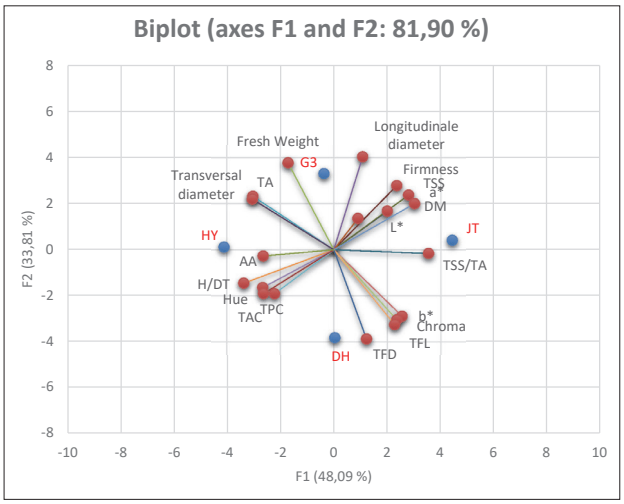

Figure 2. Dispersion of the different observations in a PCA Biplot (81.90% of the total variance explained) based on the main carpometric and qualitative indices of four kiwi cultivars.

The total polyphenol content (TPC) in JT, G3, and DH was 71, 75, and 129% higher than in HY, respectively.

The DH cultivar presented the highest total flavonoids (TFD) and total flavonols (TFL) (Table 6) due to the red pigmentation of the inner pulp.

The total antioxidant capacity (TAC) was lowest in HY, whereas it was similar among JT, G3, and DH and was over two-fold higher than that of the HY cultivar.

Principal component analysis (PCA) provided a broader view of the differences between the different cultivars in the environment where the experiment was conducted. It is possible to observe how the first two factors (F1 and F2) correspond with the high percentage of variance (81.90%), which ensures that the maps based on the first two factors offer a good quality projection of the initial multidimensional table (Figure 2).

Accordingly, the maps based on the first two factors offer a good-quality projection.

The squared cosine shows the importance of a factor (principal component) for a given observation (Abdi and Williams, 2010); indeed, only observations with a high cos^2 (*i.e.,* close to 1, highlighted in bold) are well represented by the principal component (factor). The most representative contributions (%) and cos^2 of the different variables are shown in bold (Supplemental Table S1; Supplemental Information of F2).

Results indicate that TSS/TA (10.62%), relative length (9.57%), TA (7.82%), and TD (7.74% transverse diameter) were well connected to the F1 axis. In fact, the greater the

Table 6. Fruit nutraceutical parameters [total polyphenols content (TPC), total flavonols (TFL), total flavonoids (TFD), total antioxidant capacity (TAC), ascorbic acid (AA); total chlorophyll (TChl); total carotenoids (TCar)] of the three *A. chinensis* cultivars ('Jintao', 'Gold3', and 'Donghong') and one *A. deliciosa* cultivar ('Hayward').

Cultivar	TPC (mg GAE g^{-1} FW)	TFL (mg quercetin g^{-1} FW)	TFD (mg quercetin g^{-1} FW)	TAC (µmol Trolox g^{-1} FW)	AA (mg ascorbic acid 100 mL^{-1})	TChl (µg mL^{-1})	TCar (µg mL^{-1})
Donghong	1.41a ± 0.09	3.31a ± 0.16	0.83a ± 0.03	10.77a ± 1.29	115.55a ± 1.98	0.274b ± 0.15	0.309b ± 0.07
Gold3	1.14a ± 0.07	2.11b ± 0.11	0.23b ± 0.01	8.45ab ± 0.35	118.07a ± 10.02	0.006d ± 0.01	0.137d ± 0.01
Jintao	1.17a ± 0.05	1.77b ± 0.13	0.28b ± 0.02	7.26b ± 0.78	108.30a ± 4.76	0.09c ± 0.01	0.192c ± 0.02
Hayward	0.65b ± 0.02	2.96a ± 0.08	0.48b ± 0.03	4.52c ± 0.16	61.86b ± 1.81	1.572a ± 0.21	0.367a ± 0.05

Different letters indicate significant differences ($P \leq 0.05$) between cultivars; n.s.: not significant.

cos^2 or the contribution of the variables, the greater the connection with the corresponding axis. In contrast, fruit length (13.75%), fresh fruit weight (12.02%), and total flavonoid content (12.72%) were closely connected to the F2 axis. Finally, the F3 axis was closely related to lightness (24.35%) and DM (15.64%). The HY and JT cultivars were closely connected to the F1 axis (45.99 and 53.63%, respectively), whereas the DH (56.86%) and G3 (42.43%) cultivars were connected to the F2 axis (Supplemental Table S2; Supplemental Information of F3).

The biplot (Figure 2) can be considered as the final objective of PCA. It is possible to observe the simultaneous representation of the variables and observations in the PCA space; the HY and G3 cultivars had superior results regarding fruit biometric properties. On the other hand, the DH cultivar performed the best in total flavonoid and flavonol contents, while JT had the highest soluble solid content and the highest sugar/acid ratio.

Conclusion

The experiment was conducted to determine the quality characteristics of three newly introduced yellow-fleshed *Actinidia* cultivars (*A. chinensis* Planch.) compared with the 'Hayward' cultivar, the main green-fleshed *A. deliciosa* (A. Chev.) C.F. Liang & A.R. Ferguson cultivar in one of the world's main kiwi-producing countries.

Apart from pulp colour differences, the four cultivars differed significantly from each other in terms of carpometrics, maturation indexes, and nutraceutical parameters in the trial's environment.

In particular, the HY and G3 cultivars were characterised by the best carpometric parameters. On the other hand, the DH cultivar showed the best performance concerning some nutraceutical aspects, such as total flavonoid and flavonol content, which could be attributed to the characteristic reddish veining around the central axis (modiolus) of the fruit. The JT cultivar differed mainly regarding maturation indexes, containing a higher concentration of soluble solids and a higher sugar/acid ratio.

Acknowledgments

We would like to thank Adornato D., Borgese D., Larocca F., Scarano M., Zangari F., and Zito D. for their valuable collaboration.

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Received: Jan. 31, 2021
Accepted: Jul. 5, 2021

Addresses of authors:
G. Gullo[1,*], A. Dattola[1], V. Vonella[1], A. Allegra[2] and R. Zappia[1]
[1] Department of Agraria, Mediterranean University of Reggio Calabria, Loc. Feo di Vito, 89024 Reggio Calabria, Italy
[2] Department of Agriculture, Food and Forestry Sciences, University of Palermo, Viale delle Scienze, 90128 Palermo, Italy
* Corresponding author; E-mail: ggullo@unirc.it.

Supplemental Information

Supplemental Information – Table S1. Contribution and cosine (cos^2) values of the variables for the formation of F1 and F2 and F3 of the PCA. The most representative contributions (%) and cos^2 of the different variables are shown in bold.

Variables	Contribution of the variables (%)			Squared cosines of the variables		
	F1	F2	F3	F1	F2	F3
Fresh weight (g)	2.467	**12.028**	0.056	0.225	**0.773**	0.002
Longitudinal diameter	0.984	**13.756**	0.768	0.090	**0.884**	0.026
Transversal diameter	**7.738**	4.556	0.008	**0.707**	0.293	0.000
Relative length	**9.577**	1.790	0.289	**0.875**	0.115	0.010
DM %	3.387	2.374	**15.646**	0.309	0.152	**0.538**
Firmness (kg^{-1})	**4.690**	6.561	4.362	**0.429**	0.421	0.150
TSS (°Brix)	**6.610**	4.769	2.607	**0.604**	0.306	0.090
TA (%)	**7.826**	4.069	0.684	**0.715**	0.261	0.024
TSS/TA	**10.620**	0.023	0.818	**0.970**	0.001	0.028
*L**	0.685	1.554	**24.356**	0.063	0.100	**0.838**
*a**	**7.711**	3.388	2.261	**0.705**	0.218	0.078
*b**	**5.507**	7.051	1.275	**0.503**	0.453	0.044
Chroma	4.693	**7.852**	1.941	0.429	**0.504**	0.067
°Hue	**5.971**	2.288	8.940	**0.546**	0.147	0.307
TPC	4.161	3.103	**12.226**	0.380	0.199	**0.420**
TFL	4.374	**8.962**	0.715	0.400	**0.576**	0.025
TFD	1.268	**12.728**	1.933	0.116	**0.818**	0.066
TAC	**5.837**	3.083	7.813	**0.533**	0.198	0.269
AA	**5.892**	0.063	13.305	**0.538**	0.004	0.458

Supplemental Information – Table S2. Contribution and cosine (cos^2) values of the variables for the formation of F1, F2 and F3 of the PCA of the variables (cultivars). The most representative contributions (%) and cos^2 of the different variables are shown in bold.

Variables	Contribution of the variables (%)			Squared cosines of the variables		
	F1	F2	F3	F1	F2	F3
Donghong	0.004	**56.862**	18.134	0.000	**0.854**	0.146
G3	0.368	**42.438**	**32.195**	0.009	**0.705**	**0.286**
Hayward	**45.992**	0.048	28.960	**0.808**	0.001	0.191
Jintao	**53.636**	0.653	20.712	**0.867**	0.007	0.126