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Yield affects qualitative kiwifruit characteristics and dry matter content may be an indicator of both quality and storability

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ABSTRACT

Yield and fruit characteristics from nine orchards of the cultivar 'Hayward' were investigated in 2007–2008. The two-year average yield ranged from 24 t/ha to 49 t/ha. Yield was negatively related ($P \leq 0.01$) to fruit dry matter content (DMC) and total titratable acidity (TTA) at harvest and total soluble solids (TSS) and flesh firmness after 5 months of storage. Fruit DMC at harvest was positively related to TSS ($P \leq 0.001$) and flesh firmness ($P \leq 0.01$) after 5 months of storage. At harvest, fruit DMC was also positively related ($P \leq 0.001$) to non-structural carbohydrate content (glucose + fructose + sucrose + starch); moreover, the non-structural carbohydrate content was positively related ($P \leq 0.05$) to TTA and citrate and malate contents. Fruit DMC at harvest was also positively related ($P \leq 0.05$) to the content of structural material, estimated as the difference between DMC and the measured non-structural carbohydrates and titratable organic acids. The content of fruit structural material at harvest was positively related ($P \leq 0.05$) to flesh firmness after 5 months of storage. After 5 months of storage, also the TSS was positively related ($P \leq 0.01$) to the flesh firmness. Finally, there was a positive relationship ($P \leq 0.05$) between fruit starch content and flesh firmness after 5 months of storage. The results showed that a very high fruit load can have negative effects on fruit DMC and TTA at harvest and TSS and flesh firmness after storage. Moreover, a higher DMC, besides being related with a higher TSS in ripe fruits, was also associated with a higher TTA and organic acids content and the retaining of higher flesh firmness during storage. This indicates that fruit DMC may be an indicator of both eating quality and storability of kiwifruits.

1. Introduction

Consumer acceptance for ripe kiwifruits (*Actinidia deliciosa* (A. Chev.) C.F. Liang and A.R. Ferguson, cultivar 'Hayward') is largely determined by the size, sugar concentration and sugar-acid ratio, with fruit firmness and fruit volatile content also being important (Jaeger et al., 2003; Marsh et al., 2004). Recent investigations have shown that the dry matter content (DMC), expressed as percentage, of unripe fruit at harvest is related to starch content at harvest and soluble solids concentration in ripe fruit (Richardson et al., 1997; Velemis et al., 1997; Jordan et al., 2000). Moreover, it has been shown that kiwifruits with high soluble solids content when ripe are more acceptable to consumers, suggesting that DMC can be used as a measure of potential sweetness and flavour of ripe fruit, that is, as an indicator of eating quality (Burdon et al., 2004; Crisosto et al., 2012). As a result of this, to establish the price (particularly in New Zealand), kiwifruits, besides being graded by size (which remains an important determinant for price), are now more and more evaluated on the basis of DMC. This, also because there is no general correlation between fruit fresh weight (which is related to size) and DMC across all fruit populations, as the correlation is dependent on cultural and seasonal conditions (Woodward and Cleawater, 2008).

Organic acids are other important constituents in determining sensorial qualitative characteristics (Marsh et al., 2004). In 'Hayward' kiwi, during storage and ripening the titratable acidity changes little (Matsumoto et al., 1983; MacRae et al., 1989) or decreases (Ben-Arie et al., 1982; Tombesi et al., 1993; Crisosto and Crisosto, 2001), depending on growing location conditions. Until now, very little information is available on the

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relationships between organic acids and other kiwifruit constituents and on factors affecting them in the fruits (Harker et al., 2009).

Flesh firmness is the primary indicator of kiwifruit eating ripeness and decreases from 80 to 100 N at harvest (measured with a penetrometer with a 8 mm plunger) to a relatively optimal eating range of 5–10 N (Beever and Hopkirk, 1990). Pulp firmness can also be considered the most important indicator to establish the storability of fruit. During storage, values up to around 2.5 N ensure safe manipulation of the fruit for successive commercialization, whereas when firmness decreases, the fruit is more susceptible to damage (Costa, 2003). Therefore, the most valuable fruit is that which has a slower decrease in firmness during storage ripening, because it can be stored longer and commercialised at high prices in periods when the offer is low. Hence, flesh firmness can be considered as a very important indicator for kiwifruit storability.

Several factors affect fruit DMC. At harvest, it resulted enhanced by warm springs, cool summers and warm autumns (Snelgar et al., 2007). Different canopy management styles influence fruit DMC (Mowat and Maguire, 2007). Inappropriate pruning of spring/summer canopy stimulates significant re-growth and can result in small fruit size and DMC (Woodward and Patterson, 2008), as competition for carbohydrates between vegetative re-growth and fruit growth can significantly limit the attainment of high fruit DMC (Minchin et al., 2010; Snelgar et al., 2010). In general, pruning techniques that minimise vegetative re-growth along with the use of low/medium vigour approaches to canopy construction, strongly grounded in the "leader pruning" technique (Miller et al., 2001; Thorp et al., 2003), facilitate increases in both size and DMC of the fruit (Patterson and Currie, 2011). The use of an anti-hail net, which increases the percent of scattered light compared to normal ambient light, has been reported to give a higher fruit DMC and soluble solids concentration (Basile et al., 2008), whereas overhead shading with windbreak nets was found to reduce fruit fresh weight, soluble solids and flesh firmness (Snelgar and Hopkirk, 1988). Several studies have shown the need for a suitable leaf-to-fruit ratio to support adequate fruit growth and dry matter accumulation (Snelgar et al., 1986; Snelgar and Thorp, 1988; Cruz-Castillo et al., 2010). Low leaf-to-fruit ratios in girdled shoots resulted in lower DMC (Famiani et al., 1997a). The application of summer trunk girdling was effective in increasing fruit DMC and generally this technique proved to be sustainable (Patterson and Currie, 2011). There is scarce information available on the influence of fruit load on fruit DMC. Famiani et al. (1997b) and Patterson and Currie (2011) reported that a large variation of crop load corresponded to little change in the percentage of dry matter. Growth regulators (cytokinin and auxinic compounds) have proven to significantly increase fruit size and productivity (Patterson et al., 1993; Antognozzi et al., 1996; Famiani et al., 1999, 2002, 2007), but they often result in a reduction in DMC, especially when used at relatively high concentrations/amounts per hectare (Famiani et al., 1997c).

At the farm level, the above-reported factors affecting the yield and fruit DMC can be combined in different ways, according to the farm management strategy, and thus there can be a large variability in terms of production and fruit quality.

A study was carried out, in 2007 and 2008, in central Italy, to evaluate differences in the quality and storability of kiwifruits obtained from orchards characterised by different yield levels and the relationships between different fruit qualitative characteristics, particularly between DMC and other fruit characteristics. The main goal was to establish if fruit DMC can be used as a unique index to establish both eating quality and storability of the fruit; the latter indicated by the retaining of a higher flesh firmness during storage.

2. Materials and methods

The investigation was carried out in the Lazio Region, which is the most important area for kiwifruit production in Italy (about 37%, which corresponds to about 10% of the world production) (Testolin and Ferguson, 2009).

The area is very suitable for the cultivation of kiwifruit because the climate is mild (frost is very rare during spring and autumn) and temperatures during winter are never dangerous for the vines. Yearly rainfall ranges from 800 to 1200 mm. The wind speed is rarely dangerous. The soils of the orchards studied were fertile and suitable for kiwi production: pH around neutrality, limestone absent or present in trace amounts, organic matter between 2.5 and 4%, nutrient (N, K, P, Mg, Ca, Fe) levels medium-high.

In this area, the production can be certified through the Protected Geographic Denomination (PGI) "Kiwi Latina", but this implies respecting the rules regarding the characteristics of the product (size and absence of visible defects) and the yield, which must be <33 t/ha.

The study was carried out in 2007 and 2008, by evaluating the yields and fruit qualitative characteristics of the cultivar 'Hayward' in nine orchards, chosen from among the farms of members of the APOFRUIT cooperative, considered representative for the production of the "Kiwi Latina" area, which is characterized by:

- more than 90% of the orchards trained to the Pergolette system;
- predominance of the cv. 'Hayward' (*Actinidia deliciosa*);
- about 90% of the orchards cultivated according to the integrated or conventional cultivation methods and about 10% according to the organic cultivation system;
- yields ranging from 15 to 55 t/ha.

The orchards were chosen with the help of the APOFRUIT cooperative. All the orchards were constituted by adult vines. The obtained yields were not the result of manipulations done for the purpose of creating different levels of fruit loads, but were mainly the result of different agronomical factor combinations. In Table 1 a summary of the yields and main structural and management characteristics of the orchards used for the investigation is reported.

In each orchard, fruit was harvested when the total soluble solids was around 7 °Brix.

The following data were collected annually:

- yield (t/ha), determined by weighing the whole production of each kiwifruit orchard;
- fruit fresh weight at harvest, determined on 4 samples of 30 fruits each;
- flesh firmness after 5 months of storage, determined on 4 samples of 30 fruits each;
- total soluble solids (TSS) after 5 months of storage, determined on 4 samples of 30 fruits each;
- fruit dry matter content at harvest, determined on 4 samples each composed of sub-samples of 30 fruits;
- carbohydrate content (glucose, fructose, sucrose and starch) at harvest and starch after 5 months of storage, determined on 4 samples each composed of sub-samples of 30 fruits;
- total titratable acidity and citrate and malate contents at harvest, determined on 4 samples each composed of sub-samples of 30 fruits.

Fruits were stored in normal atmosphere at $T = 0 \pm 0.5\,^{\circ}$C.

Fruit flesh firmness was determined with a hand-held penetrometer (Effe.gi, Ravenna, Italy) with an 8 mm plunger in two opposite positions around the equator of each fruit after removal