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Combining quality and antioxidant attributes in the strawberry: The role of genotype

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ABSTRACT

The nutritional value of fruit has been widely studied and is demanded by consumers, especially for protection against cardiovascular disorder, cancer and other diseases, as well as for general health benefits. These benefits can also be ascribed to the total antioxidant capacity (TAC) of fruit.
Fruit nutritional quality can be described by a standard quality parameter and the analyses of nutritional parameters, such as antioxidant capacity (and specific related compounds). In this study, firmness, colour, soluble solids content and titratable acidity were considered as quality parameters and TAC and total phenolic content as nutritional parameters. All these attributes were screened in 20 strawberry genotypes (cultivars and selections) for the selection of new improved genetic material (offspring) originating from different cross combinations, including an F1 *Fragaria virginiana* spp. *glauca* among parents.
Results indicate that the effect of the genotype on strawberry nutritional quality is stronger than that of the cultivation conditions. However, commercial cultivation did not show a high range of variation of fruit nutritional quality, particularly for the nutritional parameters.
The study of offspring originating from different cross combinations showed that fruit nutritional quality can be considered an inheritable trait and that the variability of fruit nutritional quality among commercial cultivars can be improved by breeding.
Finally, results demonstrate the role of *F. virginiana* spp. *glauca* as an important genetic source of the fruit nutritional quality.

1. Introduction

In recent decades, agronomic research has set priorities to obtain high yield, better resistance to disease and transportation and longer shelf-life of fruit. Thus, the breeding programme of fruit has been aimed at improving the yield and fruit size, the resistance to diseases and pests, the adaptation to particular growing systems and the harvesting speeds (i.e. reducing harvesting costs). Recently, research has been focused on the quality of fruit (sensorial and nutritional).

Fruit have long been regarded as having considerable health benefits due to their nutritional attributes, and in particular their antioxidant activity against cellular oxidation reactions. The positive effects of fruits may depend on the high amounts of several antioxidants (Ames, Shigens, & Hagen, 1993; Cohen, Kristal, & Stanford, 2000; Cook & Samman, 1996; Halvorsen et al., 2002; Steinberg, 1989). These benefits have stimulated research to investigate the total antioxidant capacity (TAC) of fruit and vegetables and definitely contribute to preventing or suppressing disease-like states *in vitro* (McDougall, Dobson, Smith, Blake, & Stewart, 2005) and *in vivo* (Ramirez-Tortosa et al., 2001). TAC is strongly affected by the type of fruit, the species and the variety within species. Among fruit species, strawberries have more TAC (from 2- to 11-fold) than have apples, peaches, pears, grapes, tomatoes, oranges or kiwifruit (Scalzo, Politi, Pellegrini, Mezzetti, & Battino, 2005a). Genotype-variety is the major factor in determining fruit nutritional quality, but it is also affected by crop conditions (environmental and cultivation techniques), ripening season, pre-harvest and post-harvest conditions, shelf-life and processing (Cao, Verdon, Wu, Wang, & Prior, 1995; Connor, Luby, Tong, Finn, & Hancock, 2002; Prior et al., 1998; Proteggente et al., 2002; Wang, Cao, & Prior, 1996).

TAC of the strawberry and its by-products depends mainly on the high vitamin C content (Guo et al., 2003), but also on contents of polyphenols, flavonoids and anthocyanins (Proteggente et al., 2002).

Abbreviations: TAC, Total antioxidant capacity; SS, Soluble solid content; TA, Titratable acidity; FW, Fresh weight; TPH, Total phenolic content; TEAC, Trolox equivalent antioxidant capacity assay; FRAP, Ferric reducing antioxidant power assay.

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A greater consumption of, and vegetables is considered as one way of increasing the intake of antioxidants, and strawberries, like other berries, represent the most important source of bioactive compounds with antioxidant activity (Deighton, Brennan, Finn, & Davies, 2000; Prior, 1998; Proteggente et al., 2002; Scalzo et al., 2005a). Accordingly, the increase of consumption of berries richer in "healthy compounds" is seen as an appropriate strategy for improving human health.

The increase of the level of antioxidants in fruit, through breeding and/or biotechnology, is an important option to support a higher antioxidant intake, even when the consumption of fruit is low. If nutritional components are also combined with high sensorial fruit quality the consumer health can be further improved by increased consumption.

The breeding approach can succeed if the variability and heritability of the TAC trait indicate the possibility of achieving breeding progress. The availability of genetic diversity within compatible species of any given crop will enhance improvement (Connor, Stephens, Hall, & Alspach, 2005). The biotechnological approach is now an integrative option to extend this improvement, but it is related to the knowledge of the molecular tools able to promote more general increases in several metabolites through the modification of specific biosynthetic pathways (Della Penna, 2001). However, the success of both breeding and biotechnological approaches is related to knowledge of the most useful wild and cultivated genetic diversity.

The effect on the nutritional quality of the strawberry is well known (Azodanlou, Darbellay, Luisier, Villettaz, & Amadò, 2003; Meyers, Watkins, Pritts, & Liu, 2003; Olsson et al., 2004; Wang, Zheng, & Galletta, 2002), but few genotypes are well characterised for these important features. Furthermore, only limited knowledge is available on the possibility of improving strawberry nutritional traits by breeding. In berries there are some results, and moderate heritabilities for TAC, total phenolic content (TPH) and anthocyanin content were demonstrated in blueberries and raspberries (Finley, 2005; Hancock et al., 2002; Heinonen, Meyer, & Frankel, 1998).

In this work strawberry nutritional quality was studied by considering firmness, colour, soluble solids content (SS) and titratable acidity (TA) as quality attribute parameters, and total antioxidant capacity (TAC) and total polyphenols (TPH) as nutritional parameters. The above mentioned parameters were used for screening 20 strawberry genotypes and selecting new genetic material derived from a breeding programme including six families derived from cross combination performed with parents selected for their highest nutritional quality.

2. Materials and methods

2.1. Chemicals

Bromothymol blue, sodium hydroxide, ethanol, hydrochloric acid, glacial acetic acid, Folin–Ciocalteu phenol reagent and anhydrous sodium carbonate were purchased from Fluka Chemie GmbH (Buchs, Switzerland). 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) diammonium salt (ABTS), 6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid (trolox), potassium persulfate, sodium acetate trihydrate, ferric chloride hexahydrate, 2,4,6-tripyridyl-*s*-triazine (TPTZ), and ferrous sulphate heptahydrate, 3,4,5-trihydroxybenzoic acid (gallic acid) were purchased from Sigma-Aldrich (Sigma–Aldrich s.r.l., Milan, Italy).

2.2. Plant genetic material

Strawberry fruit nutritional quality was analysed in plants cultivated in open field experimental trials, including plots for cultivars, advanced selection and plots for seedling selection.

For two harvest seasons (2003 and 2004) 16 cultivars (of international and national commercial interest), three advanced selections of *Fragaria x ananassa* and a F1 advanced selection from the inter-specific cross *F. x ananassa x F. virginiana* spp. *glauca*, were evaluated. All genotypes were grown in a complete randomised block, with four replicates of 10 plants for each plot. Furthermore, a 2 year evaluation (2003 and 2004) was carried out on seedlings (single plant) from six families from different cross combinations (nine seedlings from each family) (Table 1).

2.3. Quality parameters

Quality parameters were studied on undamaged fruit samples (300–600 g), including pooled fruit of the 3rd, 4th and 5th main harvests, from each repetition of the variety plots, selections and from seedlings. Fruit colour firmness, soluble sugar and titratable acidity were measured on the same day of each harvest. Colour was determined for two sides of 10 ripe undamaged and uniform fruit by using the Minolta-Chromameter reflect II, that includes three parameters: L* (Luminance) a* (red tone) and b* (yellow tone). Data on colour were reported as L* and chroma index $[(a^{*2} + b^{*2})]½$. High chroma index means pale fruit and low chroma index dark strawberries. Firmness (g) was measured by using a hand-held penetrometer with an 8 mm piston. SS were determined using a hand-held refractometer and results are reported as °Brix. TA was determined from 10 ml of juice diluted with distilled water (1:2 v/v) and titrated with 0.1 N NaOH, to pH 8.2, and expressed in mEq of NaOH per 100 g of fruit.

2.4. Nutritional parameters

2.4.1. General

Nutritional parameters (TAC and TPH) were studied on undamaged fruit samples (300–600 g), including pooled fruit of the 3rd, 4th and 5th main harvests. These fruit samples were collected for each replicate of the variety plots, selections and from single seedlings, then placed in polyethylene bags and frozen at −20 °C prior to extraction under reduced-light conditions. Frozen fruit samples were homogenized (with a T25 Ultraturrax blender) with solvent solution (ethanol/water, 80:20 v/v) and extracts (Scalzo et al.,

Table 1
Cross combination of each family

Family	Maternal (M)		×	Paternal (P)	
	Genotype	Species		Genotype	Species
1	Paros	*F. x ananassa*	×	Queen Elisa	*F. x ananassa*
2	Onda	*F. x ananassa*	×	AN93.371.53	*F. x ananassa*
3	Queen Elisa	*F. x ananassa*	×	Sveva	*F. x ananassa*
4	AN 94.414.52	*F. x ananassa x F. virginiana glauca*	×	91.143.5	*F. x ananassa*
5	Sveva	*F. x ananassa*	×	Patty	*F. x ananassa*
6	AN 94.414.52	*F. x ananassa x F. virginiana glauca*	×	Onda	*F. x ananassa*