



Genotypic and environmental effects on flavor attributes of ‘Albion’ and ‘Juliette’ strawberry fruits



Kavitha Samykanno^a, Edwin Pang^a, Philip J. Marriott^{b,*}

^a School of Applied Sciences, RMIT University, GPO Box 2476V, Melbourne, Victoria 3001, Australia

^b Australian Centre for Research on Separation Science, School of Chemistry, Monash University, Wellington Road, Clayton, Victoria 3800, Australia

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ABSTRACT

This work is aimed at investigating the genotypic and environmental effects on flavor attributes of two strawberry varieties, in particular, the Australian variety *Juliette* and the Californian variety *Albion*, when cultivated in the open field. Flavor quality parameters (i.e. pH, titrateable acidity, total soluble solids content and sugar/acid ratio) and volatile compositions of these two genotypes were evaluated over ten harvest dates in one growing season. Correlations have been established between these flavor attributes with variations in air and soil temperatures, photosynthetically active radiation, relative humidity, soil moisture, and rainfall, during the growing season. While genotype was the major source of phenotypic variation for pH, titrateable acidity and sugar/acid ratio, the total soluble solids content was more dependent on environmental conditions during production than on genotype. Fluctuations in soil and air temperatures, in particular, were found to significantly influence the total soluble solids content of strawberries. Furthermore, the effect of genotype was, for many volatile compounds, stronger than that of the environment. The genotype-by-environment interactions were highly significant for the four quality parameters, as well as for a majority of the volatile compounds. A set of environmental conditions have also been identified, which may be conducive for the production of highly flavorsome strawberries.

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1. Introduction

Strawberries have a worldwide appeal to the human senses of sight, taste, and smell, which can be attributed to their attractive color, delectable flavor, and unique aroma (Chandler et al., 2012). In Australia, strawberries are grown in all six states, with Victoria, a temperate climate region, being one of the leading producers. The diversity in climate across the country, together with the cultivation of short-day and day-neutral varieties, and implementation of various planting practices, allow consumers to enjoy this fruit almost all year round (O'Connor, 2009). In recent years, local varieties such as *Juliette* and *Rubygem* have been produced, and their flavor characteristics have been rated as superior to imported varieties. However, there is still a significant reliance by Australian producers on American varieties, for example, *Albion*. Imported varieties can suffer from poor climatic adaptation, and could have inadequate quality, productivity, and pest and disease resistance (Morrison and Herrington, 2002).

Strawberry aroma is described as a combination of sweet, fruity, floral, green, buttery, and sour notes (Booth et al., 2010; Du et al.,

2011a; Tsukamoto et al., 2009). Volatile compounds are responsible for this distinctive aroma, and despite accounting for less than 0.01% of the fruit fresh mass, they can significantly influence the quality of the perceived aroma (Buttery, 1981). Sugars and acids are responsible for the sweetness and tartness of ripe strawberries, which in combination with aroma volatiles provide the characteristic strawberry flavor. Since sweetness and tartness can mask each other, the intensity of sweetness or acidity perception of fruits in general, is influenced by the sugar/acid ratio or the total content of sugars or acids (Watada, 1995).

Genetic factors and variation in environmental conditions can affect strawberry fruit quality (Himelrick and Galletta, 1990). Several studies have shown that much of the variation in fruit quality can be attributed to genotype (Crespo et al., 2010; Diamanti et al., 2009; Pelayo-Zaldívar et al., 2005; Shaw, 1990). For example, Pelayo-Zaldívar et al. (2005) reported that genotypic variation was greater than harvest date variation for pH, titrateable acidity, total soluble solids, sugars, and aroma compounds; while Diamanti et al. (2009) showed that genotype can be relevant in determining strawberry fruit nutritional quality, independent of annual climatic conditions (temperatures) in open field cultivations. However, Jouquand et al. (2008) concluded that even though genotypic variation strongly influenced volatile composition and perceived flavor, harvest date was also an important factor influencing the

* Corresponding author. Tel.: +61 3 9905 9630.

E-mail address: philip.marriott@monash.edu (P.J. Marriott).

chemical composition of strawberries as titratable acidity, soluble solids content and volatile content were found to be greatly affected by harvest date (i.e. environment and genotype-by-environment interactions). Shaw (1990) showed that soluble solids content was more dependent on environmental conditions than genetic inheritance. It has also been reported in the literature that the phenolics composition of strawberries can be significantly influenced by air and soil temperatures (Josuttis et al., 2011). Nonetheless, the way cultivars respond under a particular environment does not necessarily indicate how they may respond under a different environment (Williams, 1975). Since the bulk of the information available in the literature has been based on overseas research, there is a need to address the paucity of information available for strawberry varieties cultivated locally.

In a recent study (Samykanno et al., 2013), we reported the tentative or positive identifications and the seasonal mean peak area percentages of volatile compounds detected in the fruits of *Albion* and *Juliette* that were assumed to be representative of each of these varieties, as well as of volatile compounds that were infrequently detected in either one or both of these varieties. The present study aimed at investigating the effect of genotype, the environment, and genotype-by-environment ($G \times E$) interactions on these strawberry volatile compounds, as well as four quality parameters, namely, pH, titratable acidity (TA), total soluble solids (TSS) and TSS/TA ratio. Another objective was to determine the optimal growing conditions for the new, locally bred *Juliette* variety and imported *Albion* variety. The findings from this research may aid in the production of more flavorsome fruits from existing varieties, and may also assist in the breeding of new varieties with novel flavors.

2. Materials and methods

2.1. Strawberry samples

Ripe fruits of strawberry varieties, *Albion* (day-neutral) and *Juliette* (short-day), were harvested from an experimental site in Wandin North, Victoria (37.77°S, 145.42°E; elevation: 159 m). These two varieties formed part of a larger experiment (not discussed in the present study) where a total of eight varieties were laid out in a randomized block design with two plot replicates and 24 plants per plot. All strawberry plants were in their first year, and were cultivated in the open field. Harvest dates were November 3, November 10, November 17, November 24, December 3, December 10, December 15, December 22, December 29, 2010, and January 6, 2011, which coincided with the commercial harvesting period for the two varieties in Victoria. Fruits were available for sampling from at least one plot replicate on all ten harvest dates for each variety, and from both plot replicates on seven harvest dates for *Albion* and nine harvest dates for *Juliette*. All fruits were harvested at full maturity (completely red), immediately frozen, and stored at -86°C until ready for assessment.

2.2. Determination of strawberry flavor quality

For each strawberry variety, three independent determinations for pH, titratable acidity (TA) and total soluble solids (TSS) content of the ripe fruits were performed for samples from each harvest date. In addition, volatile compounds of strawberries from each sample were extracted using solid-phase microextraction (SPME), and analyzed in triplicate by two-dimensional gas chromatography in tandem with time-of-flight mass spectrometry ($GC \times GC$ -ToFMS). All measurements and analyses were performed following protocols described in our previous work (Samykanno et al., 2013). Note that all compound identifications are considered

tentative, unless authentic standards are available to confirm GC retention and mass spectral data.

2.3. Weather station

An 8-channel EasiData Mark 4 automated weather station (Envirodata; Queensland, Australia) was installed less than 2 m from the sampled strawberry bed. It was fitted with the following sensors: relative humidity (RH) (RH40); air temperature (T_{air}) (TA10); soil temperature (T_{soil}) (TS40); soil moisture (SM) (SM40) and photosynthetically active radiation (PAR) (PR10). Data were downloaded and accessed using EasiAccess software (v. 1.767; Envirodata, Australia). Rainfall data were obtained from the Australian Bureau of Meteorology weather observation station in Coldstream, Victoria (37.72°S, 145.41°E; elevation: 83 m), which is 5.18 km from Wandin North. Since the plants were cultivated in the open field, the fruits harvested on each of the ten sampling dates essentially developed under differing plant environment conditions. Thus, from a broad perspective, although RH, T_{air} , PAR and rainfall represent meteorological conditions and T_{soil} and SM may be dependent on weather and the cultivation technique, these six factors will henceforth be collectively referred to as environmental factors.

2.4. Statistical analyses

The 95% confidence intervals for quality parameter values were calculated with the Microsoft Excel 'CONFIDENCE' statistical function (Office 2003).

All other statistical analyses were performed using the Minitab software (v. 14; Minitab Inc., State College, PA, USA). The seasonal means for pH, TA, TSS, TSS/TA and peak area percentages of volatile compounds (detected over at least 50% of the harvest dates in *Albion* and/or *Juliette*) were used for these analyses, unless specified otherwise.

To explore the association of the flavor attributes with daily mean, minimum or maximum RH, T_{air} , T_{soil} , SM, daily mean PAR, or rainfall during the preceding weeks, Pearson product moment correlation coefficients were calculated with the 'Correlation' procedure. Environmental conditions during the preceding one week showed a higher association with flavor attributes compared to that of the preceding two weeks. In particular, flavor attributes were mostly correlated to daily mean values of the six environmental parameters, and thus, these environmental conditions were used for all further statistical analyses.

Pearson product moment correlation coefficients were calculated to identify significant correlations between the six environmental factors; quality parameters and environmental factors; and levels of volatile compounds and environmental factors.

The effect of genotype, the environment, and $G \times E$ interactions on quality parameters and levels of volatile compounds was examined using analysis of variance (General Linear Model procedure; GLM). For this analysis, data of each plot replicate and their three respective pH, TA and TSS determinations; TSS/TA calculations; and $GC \times GC$ -ToFMS replicate data for volatile compounds, were used, where possible.

Multiple linear regression analyses were performed to estimate the contributions of individual environmental factors to either a quality parameter or the level of a volatile compound.

3. Results

3.1. Variations in quality parameters between harvest dates

Figs. 1–4 illustrate the fluctuations in the various quality parameters between the harvest dates for *Albion* and *Juliette*. Fruits of

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