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Production of strawberries (*Fragaria x ananassa* Duch.) in mountain areas: a comparative evaluation of berries from two June-bearing cultivars

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Abstract: Two uniferous strawberry cultivars, 'Marmolada®Onebor' and 'Elsanta', were tested in three experimental fields located at 1,200 m asl; phenological phases and fruit quality of first and second season crops were compared. Harvesting time in the first year crop occurred 40 days later than in the second season crop. Cultivar significantly affected fruit skin brightness and chroma index, flesh firmness, titratable acidity and yield in the first season crop; the experimental field location exerted a significant effect also on fruit weight and diameter, but not on total acidity. Fruit weight was higher in the second season crop, and 'Marmolada®Onebor' fruits (22.7 g) resulted heavier than those of 'Elsanta' (19.7 g). Total solid soluble content ranged from 7.4 to 8°Brix in 'Elsanta', compared to 6.2 to 7.4°Brix in 'Marmolada®Onebor'. Neither diseases nor arthropod attacks were noticed on plants and fruits.

1. Introduction

Open-field elevation cultivation of strawberries (*Fragaria x ananassa* Duch.) is being developed for fruit production in tropical regions (López *et al*., 2002; Pirlak *et al*., 2002; Riyaphan *et al*., 2005; Pádua *et al*., 2009) and also in temperate areas (Faedi, 2010; Gambardella, 2010; Rowley *et al*., 2010). Nevertheless, little information is available on the quality of strawberries obtained from plants grown in mountain areas. A strong variability of horticultural characteristics and antioxidant profiles were observed among 12 cultivars grown at 730 m asl in the Trentino Region (Italian Alps), the most relevant attributes limiting quality being represented by poor taste and low flesh firmness (Giongo *et al*., 2006). In the same area, a study by Faedi *et al*. (2009) reported that 'Elsanta' showed the best qualitative results in the first season crop among the tested cultivars.

Two commercial, ordinary June-bearing strawberry cultivars, 'Elsanta' and 'Marmolada®Onebor', were selected for an elevation cultivation trial in the area of Abetone Mountain (Apennine) in Italy.

The present paper reports the results observed on the quality of berries of these cultivars grown in open field mountain area. Two cultivation strategies are also comparatively discussed - one based on "first season crop" (FSC), carried out in 2008, and the subsequent year (2009) "second season crop" (SSC) - as well as some aspects related to the ecological environment.

2. Materials and Methods

Location and environmental characteristics

Three experimental fields (EF1, EF2 and EF3) were established in three different locations around the Abetone pass (Apennine Mountains) in Tuscany (Italy); details of the sites are reported in Table 1. The three experimental fields had good exposure to light; all of them laid on Humic Umbrisols soils (LAMMA, 2012) with similar chemico-physical characteristics. The yearly average rainfall for the area is 2,000 mm; snow is present from late November until late spring (May). Historical average of air temperature and humidity data and rainfall for the period 2008-2009 are reported in figure 1. From an ecological point of view, the selected sites for the experiment are represented by scarcely anthropized natural grasslands, highly biodiverse in terms of flora being constituted mainly by *Festuca pucinellii*, *Trifolium thalii*, *Plantago alpina*, *Poa alpina*, *Brachypodium genuense* and *Nardus stricta,* and surrounded by forests of European beech (*Fagus silvatica*), European silver fir (*Abies alba* Mill.) and elder (*Sambucus racemosa* L.) often consociated with blueberry (*Vaccinium myrtillus* L.) (Dondini and Vergari, 2009).

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Table 1 - Description of experimental fields (EF): altitude, coordinates, soil texture, N concentration (‰), C concentration (%), pH, field capacity (F.C.) and wilting point (W.P.)

Experimental fields	Altitude (m a.s.l.)	Coordinates (N/W)	Soil texture	N‰	C%	pH	F.C. (-0,33 bar)	W.P. (-15 bar)
EF 1	1,213	N 44°08.650' W 10°41.412'	Sandy-loam	0.3	3.5	5.2	20.1	11.6
EF 2	1,250	N 44°08.517' W 10°42.043'	Loam	0.1	3.6	6.2	18.4	11.1
EF 3	1,250	N 44°07.810' W 10°45.336'	Sandy-loam	0.1	3.7	5.9	23.6	16.5

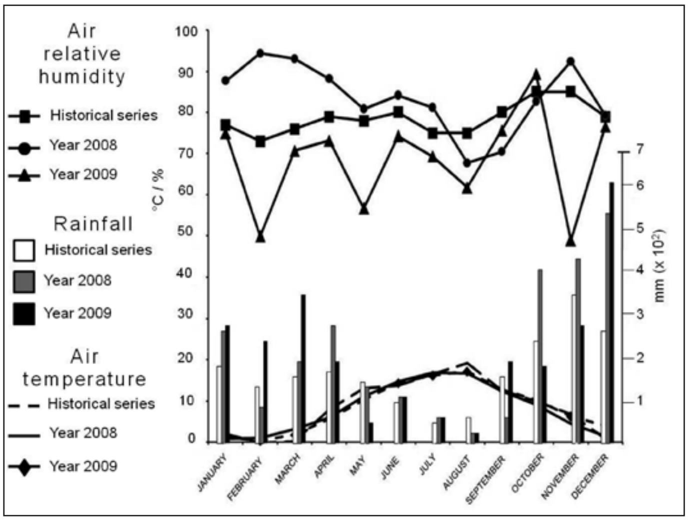


Fig. 1 - Mean air temperature (°C), relative humidity (%) and rainfall (mm) of the trial location of years 2008, 2009 and historical series (data elaborated from LAMMA).

Soil management and plant spacing

In May 2008 the soil area destined for the three experimental fields (500 m² each) was ploughed 30 cm deep and mature manure was distributed uniformly at the rate of 80 t/ha; soil was not fumigated. The strawberries were planted in parallel hill rows 110 cm apart with a distance of 30 cm between plants within the row, with a density of 4 plants/m²; the plants of each cultivar were distributed in an alternate four-row scheme for a total of eight rows for each experimental field. A black polyethylene film was used along the rows for mulching. Each plot was surrounded by guard rows.

Plant material, planting and management

One-crown homogeneous-size certified refrigerated plants of 'Elsanta' and 'Marmolada®Onebor' were supplied by a qualified commercial nursery. In early May 2008 strawberries were planted in the experimental fields, from which the FSC was obtained; the same open field unprotected, overwintered and not de-crowned strawberry plants generated the SSC in 2009. Plants were drip irrigated with 1,000 l/d average per experimental field, from flowering time up to the end of the productive season; no treatment was adopted for pest and disease control. Weeds were manually removed.

Data collection

During the two years of study (2008 and 2009), observations regarded phenological, morphological and chemical characteristics. Flowering and ripening time were recorded on one sample every five plants and reported as days from the beginning of the year. Morphological data were measured on four replicated sets of 25 ripened fruits each for every experimental unit (cultivar/location) during the period of maximum productive peak. Fruits were harvested and promptly characterized for weight and maximum diameter, skin colour, flesh firmness (two sides), fruit shape and presence of internal cavity. Weight (g) was measured with a precision balance (Sartorius TE 150/2s - SARTORIUS) and diameter (mm) with hand calliper; colour (L, a, b coordinates) was determined with a Minolta Chromameter CR200 - KONICA MINOLTA electronic colorimeter and the a and b coordinates were transformed in the chroma index $(a^2 + b^2)^{1/2}$; flesh firmness (g) was measured with a 6 mm diameter plunger hand penetrometer TR 53200. Fruit shape and presence of an internal cavity were visually assessed following the UPOV descriptor for strawberry (UPOV, 2008). Chemical parameters such as pH, titratable acidity and total solid soluble (TSS) content were assessed on samples (four replicates per experimental unit) of juice extracted from 10 fruits. Titratable acidity (meq malic acid/100 g fresh weight) was determined at pH 8 with a 0.1 N solution of NaOH, adopting a Basic 20 - CRISON pH meter; total soluble solid content (°Brix) was quantified with a hand refractometer (Atago N1 - ATAGO CO., LTD). Fruits were tasted by five experts to assess sensorial quality and flavour quality was rated on a five-score scale (1 - very weak; 2 - medium weak; 3 - medium; 4 - good; 5 - very good), while for persistence of taste 3 min after ingestion and scent intensity, a three-score scale (1 - weak; 2 - medium; 3 - strong) was adopted.

Experimental design and statistical analysis

Each of the three experimental fields was split into 16 rows (eight alternate rows per cultivar); every row held 125 plants. A two-way analysis of variance was employed to test the significance of the effects due to cultivar ('Elsanta' and 'Marmolada®Onebor') and experimental field location (EFL1, EFL2 and EFL3), both considered as independent factors, and their interaction. Duncan's test was applied for mean separation; the averages were reported with standard errors. Two-tail Chi^2 test was applied to qualitative and scale-scored parameters exposed as frequencies. SPSS Statistics 17.0 software was used for analyses; differences at $P < 0.05$ and $P < 0.01$ were considered significant and very significant, respectively.

3. Results

The ANOVA statistical significance of the different factors on the studied parameters are reported in Table 2; each of them will be discussed in the following sections.

First season crop (FSC)

Both Elsanta and Marmolada®Onebor cultivars showed the same pattern of phenological stages in the three locations; in detail the full blooming started on 8 July 2008 (day 190) and portrayed until day 203 for a total of 13 days. The first fruits of both cultivars ripened 24 days later (day 214), and harvest time closed on day 234; the period of maximum peak of ripened strawberries fell in the period 4-11 August 2008 (days 217-224) (Fig. 2).

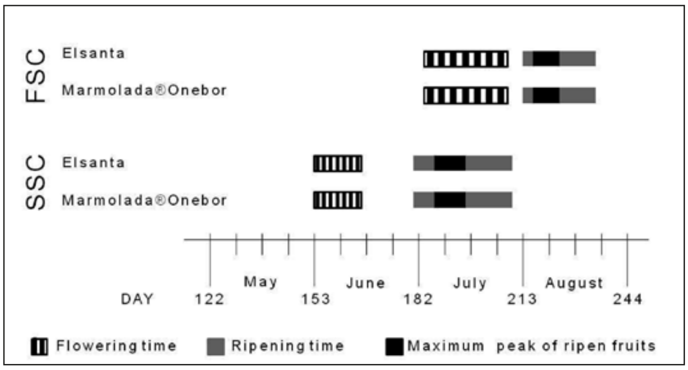


Fig. 2 - Blooming and fruit ripening time in years 2008 (FSC) and 2009 (SSC).

Average fruit weight resulted identical for both cultivars (15.0±0.4 g)(ANOVA; P = 0.69) (Table 2). Field location and its interaction with cultivar exerted a statistically significant effect on this parameter (ANOVA; $P < 0.01$), with the highest and the lowest weights of 19.1±0.7 g and 11.8±0.7 for 'Marmolada®Onebor' obtained in EF1 and EF3, respectively; for 'Elsanta' the maximum and minimum values were 15.9±0.7 g in EF1 and 13.8±0.7 g in EF3 (Fig. 3A). As expected, the fruit maximum diameter (average 32.9±6.1 mm in 'Elsanta' and 32.04±6.2 mm in 'Marmolada®Onebor') followed a behaviour similar to that observed for fruit weight, and it was affected significantly by the experimental field and its interaction with cultivar (Fig. 3A).

Table 2 - Significance of cultivar, experimental field location and their interactions on the quantitative parameters analyzed on strawberry fruits resulted from analysis of variance (ANOVA)

Attribute	Crop	Cultivar CV	Experimental field - EF	CV*EF	Replicates
Fruit weight	FSC	NS	**	**	NS
	SSC	**	**	**	NS
Fruit diameter	FSC	NS	**	*	NS
	SSC	NS	**	NS	NS
Fruit brightness (L)	FSC	**	**	*	NS
	SSC	NS	**	**	NS
Chroma index	FSC	**	**	**	NS
	SSC	NS	**	**	NS
Flesh firmness	FSC	**	*	**	NS
	SSC	**	**	**	NS
Fruit pH	FSC	NS	NS	NS	NS
	SSC	NS	NS	NS	NS
Titratable acidity	FSC	*	NS	NS	NS
	SSC	**	**	NS	NS
TSS content	FSC	NS	NS	NS	NS
	SSC	*	NS	NS	NS

NS= non significant; * = 0.05<p<0.01; **= p<0.01.

Skin colour was analysed taking into account brightness (L) and chroma index. L values ranged from 30.9 to 47.6 for 'Elsanta' and 24.7 to 47.8 for 'Marmolada®Onebor', with averages of 38±0.3 and 35.2±0.3, respectively (ANOVA; P <0.01). Fruit skin brightness showed differences of 2 units (≈ 35 against ≈ 37) due to the effect of the experimental field location (ANOVA; $P < 0.01$). Analogous results were observed for chroma index, with average values of 40.3±0.4 and 37.1±0.4 for 'Elsanta' and 'Marmolada®Onebor' (ANOVA; $P < 0.01$); similarly to skin brightness, EF exerted a very significant influence on chroma index, with a variation of ≈ 2 units.

Flesh firmness resulted statistically different (ANOVA; P<0.01) between the cultivars; the highest average value was observed in 'Marmolada®Onebor' (473.1±9 g), which is about 33% higher than the firmness of 'Elsanta' fruits (355.6±7.9 g). The experimental field location exerted a significant effect on fruit firmness (P<0.05); a 5% difference between the maximum and the minimum average values was observed.

No relevant differences were found in pH of juice, showing a value of 3.6 for both cultivars, and no effect was attributable to the location of the experimental fields. Different results were obtained for titratable acidity, which was higher in 'Elsanta' fruits (12.6±0.8 meq/100 g FW) than in 'Marmolada®Onebor' (9.6±0.4 meq/100 g FW) (ANOVA; P<0.05); location did not affect this parameter. Taking into account the total solid soluble content of strawberry juice, the cultivar Elsanta showed an average value of 7.4±0.3 °Brix, against 6.2±0.3 °Brix of

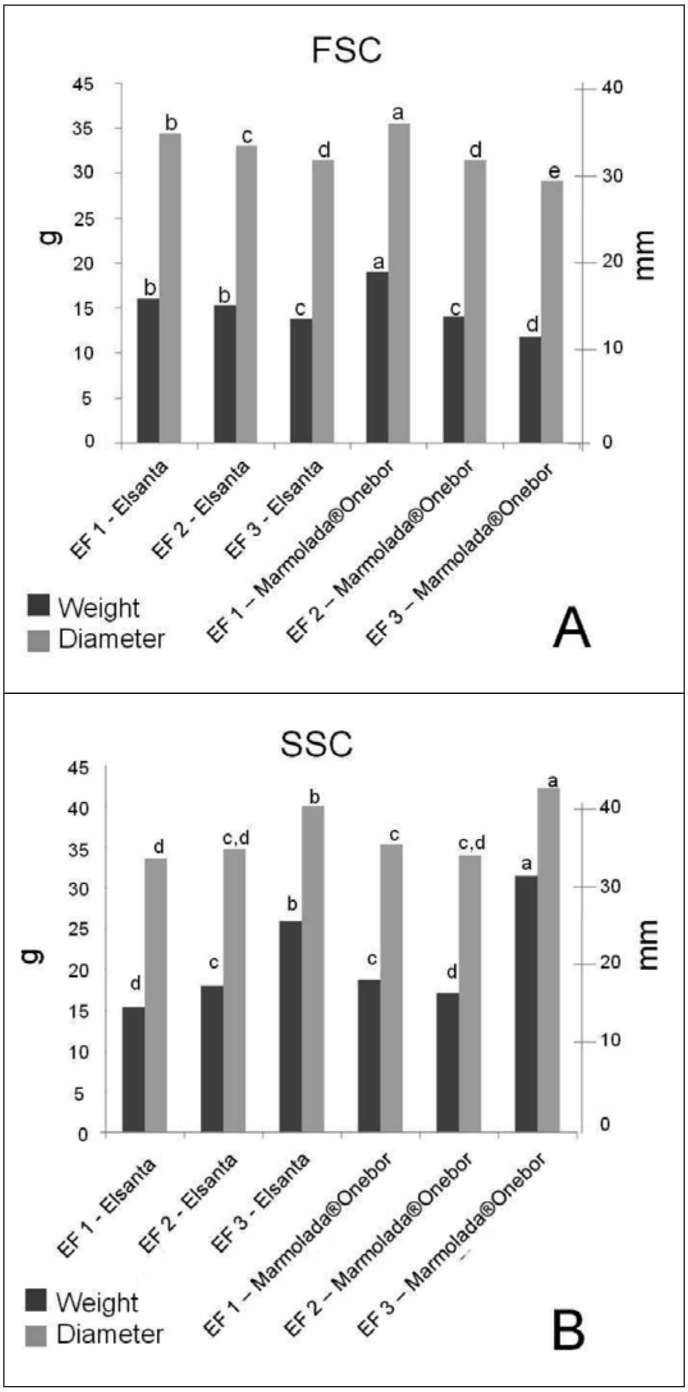
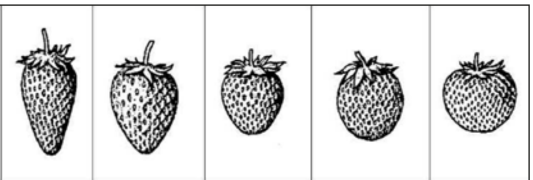


Fig. 3 - Fruit weight and diameter for 'Elsanta' and 'Marmolada®Onebor' in the first (A) and second (B) season crop observed in each experimental field (EF). Bars with different letters are statistically different (Duncan's test; P<0.05).

'Marmolada®Onebor'; such differences were not statistically significant (ANOVA; P>0.05).

The distribution of fruit shape resulted similar among cultivars; no statistical differences were observed between cultivars for conical and globose-conic classes, the most frequent fruit shapes. Significant differences (CHI[2]; P< 0.01) were found in the percentages (40% and 27%) of globose-conic fruits of 'Elsanta' and 'Marmolada®Onebor', respectively (Fig. 4).

The internal cavity was present in approximately 81% of fruits of both cultivars; a significant statistical difference (CHI[2]; P<0.01) was observed taking into account the experimental field (EF factor), since almost 100% of fruits from EF2 showed internal cavity, against about 75% of those obtained in the other two sites.



Strawberry shape		LONG CONIC	CONICAL	GLOBOSE - CONIC	GLOBOSE	OBLATE
FSC	Elsanta	4	48	40	6	2
	Marmolada® Onebor	6	55	27	7	5
	Significance	NS	NS	*	NS	NS
SSC	Elsanta	1	26	68	4	1
	Marmolada® Onebor	1	58	36	3	2
	Significance	NS	*	*	NS	NS

Fig. 4 - Fruit shape distribution (%) of 'Elsanta' and 'Marmolda® Onebor' for years 2008 (FSC) and 2009 (SSC). CHI[2] statistical differences within columns: NS= not significant; * significant (P<0.05).

The distribution of fruits for each cultivar taking into account the quality of taste, resulted as an average value of five taste assessors, is reported in figure 5A. 'Elsanta' showed a percentage (86%) of fruits of acceptable quality (namely the sum of the "medium", "good" and "very good" classes) which was higher than the one observed in 'Marmolada®Onebor' (63%); such difference resulted non significant (CHI[2]; P>0.05). On the other hand, no relevant effect was exerted by the experimental field location. The fruits of 'Elsanta' showed a higher percentage of fruits with medium (69%) and strong (21%) persistence of taste 3 min after ingestion, against 61% and 3% observed on 'Marmolada®Onebor' fruits. The effect of the location of the experimental field was not statistically significant for this parameter, but the best results were obtained in EF2. A similar situation was observed for scent intensity, which resulted superior in 'Elsanta' fruits compared to those of 'Marmolada®Onebor', with a higher percentage of strongly scented fruits (26%) against (8%)(CHI[2]; P <0.01)(Fig. 6A); the location producing more fruits with strong scent was EF2.

Second season crop (SSC)

Full blooming of 'Elsanta' and 'Marmolada®Onebor' was observed in the three plots on 29 May (day 150) and it finished 14 days later (day 164). The first fruits ripened at day 177 (26 June 2009) and the last ripened on day 209 (28 July 2009), with the maximum peak of ripened fruits between days 186 and 192 (Fig. 2).

The highest fruit weight was observed for 'Marmolada®Onebor' (average 22.4±0.5 g) while a lower mean value was found in 'Elsanta' fruits (19.7±0.5 g)

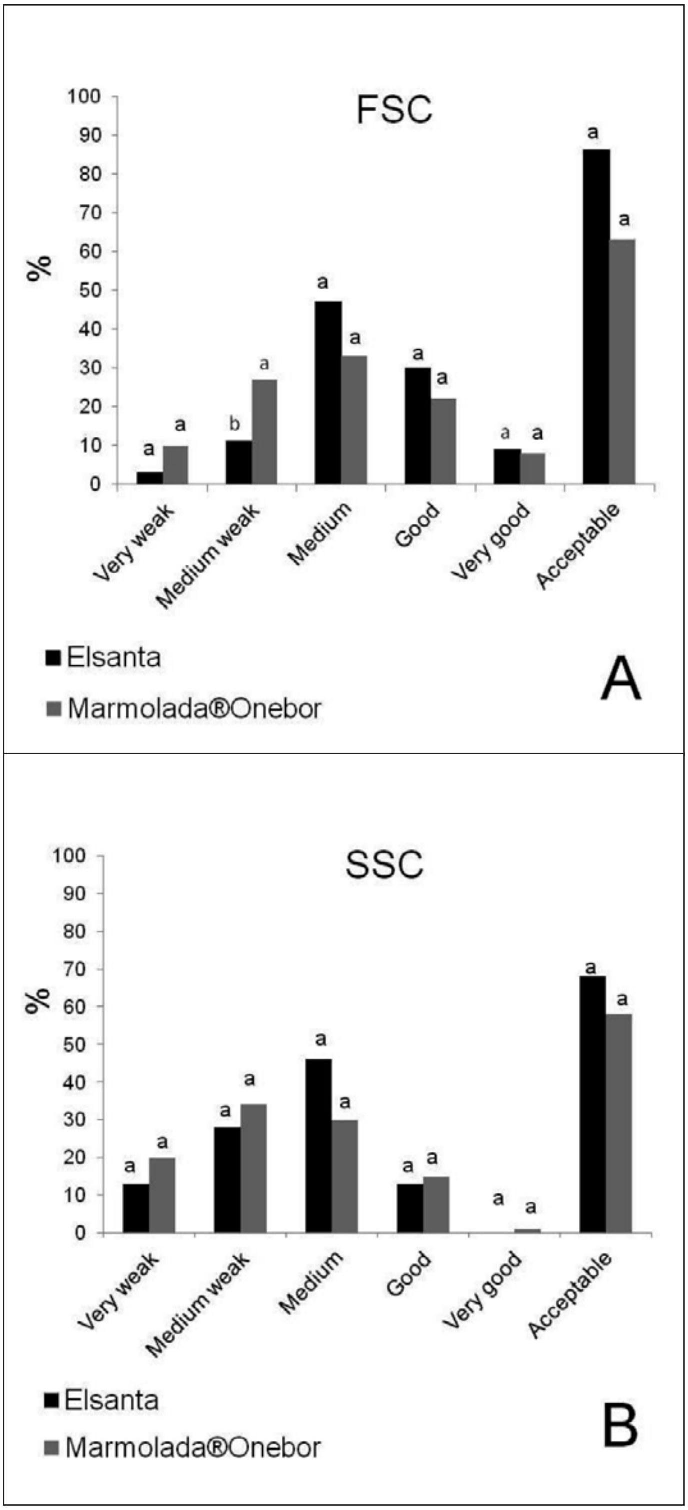


Fig. 5 - Fruit taste: distribution (%) of the first (A) and second (B) season crop strawberries for different quality classes of ‘Elsanta’ and ‘Marmolada®Onebor’. Acceptable fruit is the sum of medium, good and very good classes. Bars with different letters are statistically different (CHI^2; P<0.05).

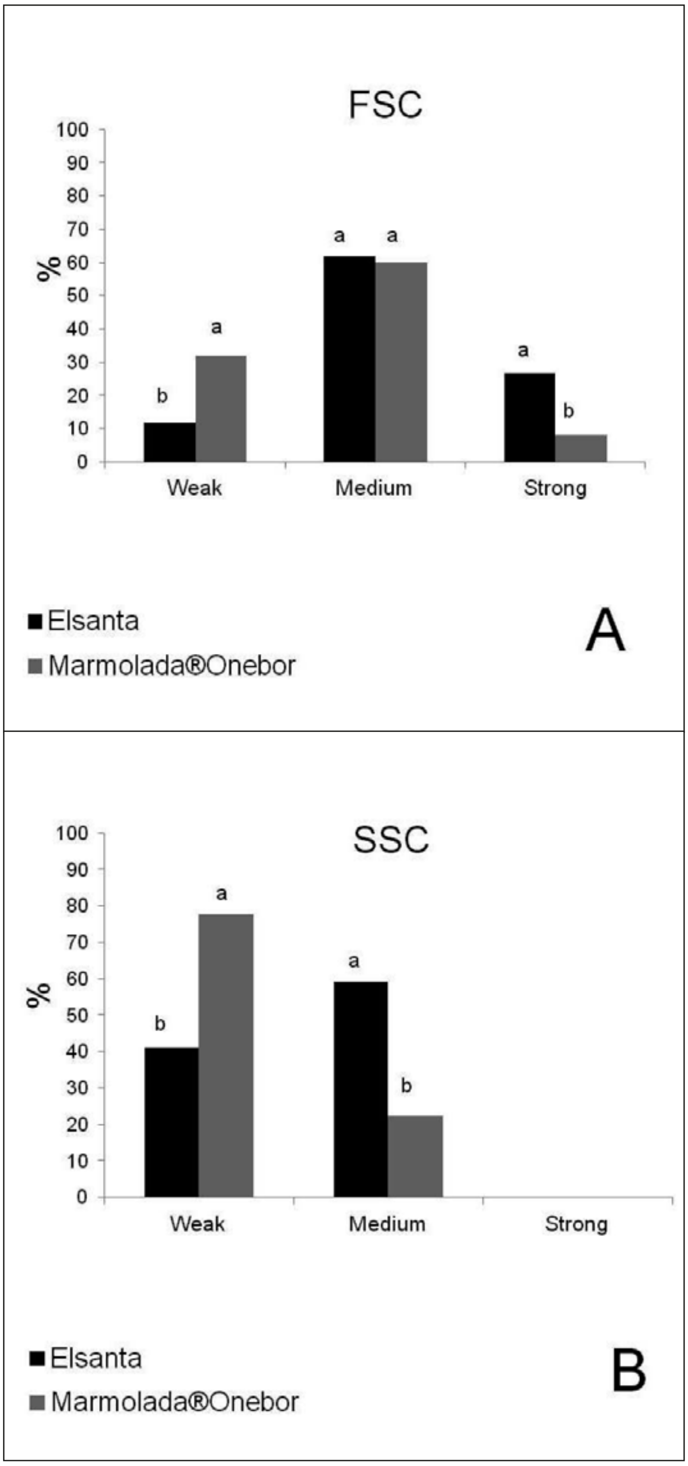


Fig. 6 - Fruit scent intensity: distribution (%) of strawberries of Elsanta and Marmolada®Onebor cultivars for the first season crop (A) and the second season crop (B). Bars with different letters are statistically different (CHI^2; P<0.05).

(ANOVA; P< 0.01). Also the experimental field location affected fruit weight very significantly, with the highest mean values observed in EF3 (28.7±0.7 g); a reduction of about 40% of this parameter was observed in EF1 and EF2. The effect of the interaction cultivar by location on fruit weight was also very significant (ANOVA; P<0.01) with the highest mean values found in fruits of ‘Marmolada®Onebor’ grown in EF3 (31.5±0.9 g) and the lowest for those of ‘Elsanta’ grown in EF1 (15.3±1.0 g).

Fruit diameter resulted practically identical between the cultivars (37.2±0.4 mm and 36.1±0.4 mm for ‘Marmolada®Onebor’ and ‘Elsanta’, respectively); in accordance with fruit weight, the greatest diameters were observed in EF3 for fruits of 'Marmolada®Onebor' (Fig. 3B).

Skin brightness (L coordinate) was similar between the cultivars, ranging from 29.3 to 47.8 for 'Elsanta' and 29.2 to 47.1 for 'Marmolada®Onebor', with averages of 37.7±0.3 and 37.3±0.3 respectively. Only field location exerted a strong effect on this parameter (ANOVA; P<0.01); skin brightness reached the highest value (39.7±0.4) in EF2, followed by EF3 (36.8±0.4) and EF1 (35.9±0.3). Similarly, chroma index of skin colour was influenced by the location of experimental field (ANOVA; P<0.01) with the highest values in fruits from EF2, decreasing then in those obtained in EF3 and EF1. The chroma index average value for fruits of 'Elsanta' was 34.3±0.5 while for 'Marmolada®Onebor' it was 33.8±0.5. The interaction of cultivar and location affected very significantly these two colour parameters (Table 2).

Taking into account fruit flesh firmness, 'Elsanta' showed the highest average (490±0.5 g) compared to that of 'Marmolada®Onebor' fruits (460.2±4.7 g)(P<0.01). The experimental field location and its interaction with cultivar exerted a very significant effect on fruit firmness (P<0.01), with differences of around 13% between the maximum and the minimum average value found in EF3 and EF1, respectively.

The juice of 'Elsanta' and 'Marmolada®Onebor' fruits showed the same pH value (3.6), while titratable acidity was affected by the cultivar and location of cultivation. 'Elsanta' showed a higher titratable acidity (average 12.8±0.6 meq/100 g FW) than that observed in 'Marmolada®Onebor' fruits (10.7±0.5 meq/100 g FW) (ANOVA; P< 0.01). Analogously, the location of cultivation exerted a very significant effect on this parameter; the highest mean value (13.5 meq/100 g FW) was found in berries obtained in EF2, against 10.9 meq/100 g FW of those harvested in EF1.

The cultivar Elsanta showed an average value of 8.1±0.7 °Brix for total solid soluble content of juice, against 7.4±0.8 °Brix of 'Marmolada®Onebor' (ANOVA; P <0.05). No significant differences were observed due to the location of the experimental field; in any case, the highest value was observed in 'Elsanta' cultivated in EF2 (8.6±0.3 °Brix); 'Marmolada®Onebor' showed the maximum value of total solid soluble content in EF1 (8±0.3°Brix).

The most frequent fruit shapes were conical and globose-conic (Fig. 4). The differences between the cultivars resulted statistically very significant (P<0.01) for both shapes; 'Elsanta' presented 68% and 26% of fruits belonging to the globose-conic and conical shapes, while in 'Marmolada®Onebor' the frequencies were of 36% and 58%, respectively (Fig. 4).

The difference between cultivars for the presence of internal cavity was non significant, with values of 35% and 45% of cases in 'Elsanta' and 'Marmolada®Onebor' respectively. The location of cultivation exerted a significant effect (Chi^2; P<0.05) on this characteristic; the lower percentage of fruits showing internal cavity was observed in EF1.

The distribution of cases for fruit taste is illustrated for both cultivars in figure 5B. Taking into account the percentage of acceptable fruits in terms of quality of taste, 59% and 46% for 'Elsanta' and 'Marmolada®Onebor' respectively, the cultivar effect resulted statistically not significant. On the contrary, the effect of the experimental field location on fruit taste was very significant: EF1 showed 72% of fruits with acceptable taste, while these values were of 44% and 18% for EF2 and EF3, respectively (CHI^2; P<0.01). The persistence of taste after ingestion resulted identical for both cultivars and the location did not exert a relevant effect on this parameter. None of the cultivars produced fruits with strong scent; 'Elsanta' showed higher percentages of fruits belonging to the medium class (59%) against 22% of 'Marmolada®Onebor' (CHI^2; P<0.01) (Fig. 6B). Taking into account the location of the experimental field, EF3 showed the worst result, with the highest percentage of fruits with weak scent (80.7%), against ≈ 55% observed in the other two fields.

4. Discussion and Conclusions

No differences were observed for flowering and fruit ripening time between cultivars and experimental fields. In 2008, the interval between planting date and flowering time corresponded to 24 days for both cultivars, which is almost half the time indicated by Perez de Camacaro *et al.* (2004) for 'Elsanta' plants grown in the UK; conversely the interval flowering-ripening time (36 days) coincided with that found by Perez de Camacaro *et al.* (2004). In the second season crop, this interval was eight days shorter for the strawberries grown in Tuscany (28 days), and the same (36 days) as in the trial reported by Perez de Camacaro *et al.* (2004). The FSC ripening time for 'Elsanta' and 'Marmolada®Onebor' cultivars showed a delay of 40 days in relation to the second year crop. This finding confirms the possibility of scheduling the strawberry harvesting time offered by elevation cultivation, as indicated by Faedi *et al.* (2009).

The average weight of FSC fruits was about 15 g for both cultivars, but experimental field and its interaction with the cultivar exerted a strong effect on this parameter. The heaviest fruits (average 19.1 g) were obtained from the plants of 'Marmolada®Onebor' grown in EF1; they weighed about 7 g more than the fruits collected in EF3. A lower magnitude difference was observed in 'Elsanta' fruits. In the second season, crop fruit weight was on average 25% higher than the value for 2008; furthermore the cultivar factor was more relevant, since 'Marmolada®Onebor' fruits (average 22.7 g) were about 3 g heavier than those of 'Elsanta' (19.7 g). A similar situation was observed by Coman *et al.* (2002) for the same cultivars grown on the north-eastern coast of the USA (19 and 14 g/fruit for 'Marmolada®Onebor' and 'Elsanta', respectively). The values obtained for fruit weight of 'Elsanta' in the second season crop are similar to those indicated by Fitogest (2011) and much higher than those observed by Giongo *et al*. (2006) in similar growing conditions and by Palha *et al*. (2009) in soilless culture. On the other hand, the fruit weight of 'Marmolada®Onebor' fruits was very close to the value indicated by Fitogest (2011). Slightly lower average weights (17.2 g) were found in a set of cultivars grown in Brazil at 1,370 m asl by Pádua *et al*. (2009), while a higher value (26.3 g/fruit) was observed for 'Marmolada®Onebor' in Cesena (Italy) on one-year-old planted strawberries (Tagliavini *et al*., 2005). The observations confirm that average fruit weight is lower in the first season crop than in the second, which is in accordance with the results of previous studies on 'Elsanta' and 'Bolero' (Perez de Camacaro *et al*., 2004). Also the experimental field influenced fruit weight with heavier fruits obtained in EF3. The opposite influence of EF3 on fruit weight in the second year crop can be attributed, more than to the intrinsic characteristics of the location (e.g. soil chemico-physical properties), to a predominant effect of the cultivar due to cumulate effects associated to the changes in vegetative growth of the second year. In strawberry, the predominant sink is represented by fruits (Olsen *et al*., 1985); fruiting affects dry-matter partitioning, hence the changes in vegetative development may significantly interfere with fruit production as suggested by Perez de Camacaro *et al*. (2004). FSC strawberries were underweight by a few grams when taking into account the optimal market values indicated by Lovati (2010). Conversely this parameter was acceptable for the second year crop. Fruit diameter resulted highly correlated with fruit weight (R^2= 0.87; P<0.01), nevertheless it was less influenced than fruit weight by cultivar effect. Again, the observed values of 'Elsanta' fruit diameter are in accordance to those indicated by Giongo *et al*. (2006).

Taking into account fruit colour, brightness resulted close or superior to the acceptable threshold of 37, as indicated by Lovati (2010) for both cultivars and for the two crops; on the other hand, chroma index was lower than the limit value (40). Colour parameters were less affected by cultivar in the second season crop; conversely experimental field was found to be a more relevant factor. During 2008 the fruits obtained in F1 showed the highest values of brightness and chroma index, while in 2009 the most attractive fruits in terms of brightness and chroma index were grown in EF2. Brightness values in both years were almost the same: chroma index was 4 points higher in 2008 than in 2009.

Flesh firmness of fruits was significantly affected by the studied factors and by their interactions. The optimal range of flesh firmness for harvesting and handling strawberries is indicated as 300-400 g (Lovati, 2010), about 20% lower than that observed for first and second season crops for both cultivars under study. The average firmness found for 'Elsanta', regardless of year and experimental field, was 423 g, approximately 25% higher than that found by Giongo *et al*. (2006) in plants grown at 730 m asl, demonstrating a good texture of the fruits at ripening time, and hence better suitability to handling and transport.

Fruit juice pH was not affected by any studied factor, resulting substantially stable with a value of 3.6 in both FSC and SSC. Titratable acidity was significantly influenced by the cultivar in both FSC and SSC, with average values of about 12.7 and 10.2 meq/100 g FW for 'Elsanta' and 'Marmolada®Onebor' respectively. Such values are within the range of 10-15 meq/100 g FW indicated as optimal for strawberries by Roudellac and Trajkovsky (2003) and Lovati (2010). Giongo *et al*. (2006), observed a higher value (13.6 meq/100 g FW) in 'Elsanta' fruits obtained in similar growing conditions; in a trial conducted in Slovenia, 'Elsanta' showed a total acid content higher than the one found for 'Marmolada®Onebor' (Sturm *et al*., 2003), which is in accordance with the results of this research. Titratable acidity was lower (7 meq/100 g FW) in the juice of 'Marmolada®Onebor' fruits collected in Cesena (Italy) from one-year-old plants (Tagliavini *et al*., 2005); location seems to have a strong effect on this parameter, as confirmed in our experiment for the second season crop where location exerted a significant influence with a maximum variation of about 30% of the amount of titratable acidity.

Taking into account the total solid soluble content of strawberry juice, the cultivar 'Elsanta' showed an average value of 7.4 and 8°Brix, against 6.2 and 7.4°Brix of 'Marmolada®Onebor', in 2008 and 2009 respectively. These results, even if higher in value, show a similar trend to those found for 'Elsanta' (about 5.8°Brix) and 'Marmolada®Onebor' (about 5.2°Brix) grown under identical conditions in Slovenia by Sturm *et al*. (2003). Similar results were obtained by Radajewska and Dejwor-Borowiak (2002) on both cultivars grown in Poland. Nevertheless, different values of total solid soluble content of 'Elsanta' fruits have been found by different authors and for plants growing in diverse areas and cultivation systems. Kovačević *et al*. (2008) noted a value of 7.2°Brix in fruits grown under organic and conventional cultivation. Palha *et al*. (2009) found values ranging from around 7.7 up to 10 °Brix on strawberries in soil less cultivation, depending on planting date, tray and bare-rooted plant type, and similar values were observed by Voća *et al*. (2007) in Croatia for the same cultivar. Giongo *et al*. (2006) recorded an average value of 8.4°Brix in fruits obtained from cultivation in buckets at 730 m asl. Lower mean values of solid soluble content (7.2°Brix) were observed by Pádua *et al*. (2009) on a different set of cultivars grown in Brazil at 1,370 m asl. The values observed for 'Marmolada®Onebor' were higher than those shown by the same cultivar grown in flat areas (4.7°Brix) (Tagliavini *et al*., 2005), thus confirming the positive influence of environmental conditions of mountain areas on fruit quality. No statistical differences were observed taking into account the experimental fields and their interaction with the cultivar, nevertheless it is worth noting that 'Elsanta' fruits obtained in EF1 reached 8.1°Brix, which is in accordance with the values found by Giongo *et al*. (2006). However the results obtained in the present study are higher than the threshold of 7°Brix, adopted as a standard quality parameter for strawberries (Roudeillac and Trajkosky, 2003). The results here obtained for 'Marmolada®Onebor' are higher than those reported by Kovačević *et al*. (2008) and Plantgest (2012) of 5.7-6.0 and 5.7 °Brix respectively.

In this study total solid soluble content was associated with taste quality, even if this sensorial parameter is influenced also by many other factors such as acidity, flavours, flesh texture, etc. 'Elsanta' fruits resulted better in taste quality than those of 'Marmolada®Onebor' for the two years of observation (Fig. 5) and in taste persistence in the FSC. Similarly 'Elsanta' fruits showed a higher percentage of fruits in the superior class of scent intensity (Fig. 6). These results are in accordance with those found by Coman *et al*. (2002) in fruits of 'Marmolada®Onebor' and 'Elsanta' grown on the north-eastern coast of the USA and with those of Radajewska and Dejwor-Borowiak (2002) in a trial conducted in Poland. Fruits of the FSC resulted better than those obtained as SSC for all the analysed sensorial attributes (taste, taste persistence and scent intensity); this result may be associated to the about 15% higher total soluble content and slightly lower titratable acidity observed in the juice of strawberries derived from the FSC, with respect to those of the SSC.

Most of consumers prefer conical, or slightly round-conical strawberries (Tirelli, 2010). The predominant fruit shapes found in the present study were conical and globose-conic; a cultivar effect was noted, but location did not seem to exert any influence on this parameter. The most frequent class of fruit shape in the FSC was conical while conversely globose-conic was predominant for the second season crop. The variation from one class to the other was more evident in 'Elsanta' fruits (Fig. 4).

The internal cavity is a morphological attribute that does not have a relevant effect on quality but may modify the shape and volume of fruits. This parameter was not cultivar-dependent but location had a significant influence on the percentage of fruits with an evident internal cavity. Furthermore, the growing system (FSC or SSC) seemed to exert a similar effect, since during the FSC around 80% of fruits showed this attribute compared to 40% in the second year crop.

'Elsanta' is considered highly susceptible to soil-born diseases and powdery mildew, while 'Marmolada®Onebor' is deemed to be less susceptible to fungal diseases (Baruzzi *et al*., 2009). Nevertheless, no disease or arthropod attacks were observed in this trial on either of the cultivars in both years of experimentation. Conversely Łabanowska *et al*. (2004) observed heavy symptoms caused by powdery mildew and strong attacks of mites (*Tetranychus urticae* and *Phytonemus pallidus* ssp. *fragariae*) on 'Elsanta' plants, while 'Marmolada®Onebor' was strongly infected by leaf spot (*Mycosphaerella fragariae*) and attacked by strawberry blossom weevil (*Anthonomus rubi*). Analogously, Hietaranta *et al*. (2004) evaluated 'Elsanta' as insufficient for resistance to pest and diseases in Nordic European countries. This means that the environmental characteristics of the area chosen for the trial exert a positive effect on plant health. This is not a secondary aspect in strawberry production, since the practices adopted to reach high yields in flat area cultivation (including a massive use of pesticides, soil fumigants and fertilizers) are in contrast with the market demand oriented towards healthy, organic and high quality strawberries (Gengotti *et al*., 2008; Mennone *et al*., 2008). Furthermore, the demand by consumers for healthy fresh fruits, rich in antioxidants, produced locally and in unpolluted environments is noticeably increasing (Tulipani *et al*., 2008). Strawberry high-altitude cultivation opens a new scenario since the ecological conditions (climate, soil, and spontaneous flora and fauna, associated with a generally low anthropized environment), seem to positively influence the nutritional properties of berries, for example increasing their polyphenol content as reported by Szajdek and Borowska (2008), and above all exert a strong influence on the amount and spectrum of harmful pests and diseases and hence on the cultural practices needed for production. Guerena and Born (2007) found that spontaneous flora alongside strawberry fields represented a shelter and a source of pollen and nectar to predators and parasites of insect pests, thus reducing the amount of damaged plants and strawberries. Furthermore, in almost natural conditions and sustainable farming systems the soils are rich in arbuscular mycorrhizal fungi which strongly contribute to counter-balance the appraisal and diffusion of soil-born diseases, such as fungi like *Fusarium, Phytophthora, Pythium, Rhizoctonia* and *Verticillium*, and nematodes (Branzanti *et al*., 2002; Harrier and Watson, 2004). Additionally, naturally fertile soils, namely in terms of organic matter content, are typical of many mountain areas. In this regard, Gonzalez and Acuña (2009) found that in strawberry cultivation a soil rich in organic matter may supply fertilization at least for the first year of establishment, hence reducing the chemical inputs which are a source of pollution to adjacent ecosystems (Tagliavini *et al*., 2005).

Strawberry high-elevation cultivation is feasible also in temperate areas as shown by this study. The main factors affecting fruit quality and productivity are related to cultivar and to location, this latter being a relevant aspect even under highly homogeneous environmental conditions. The first season crop, showing higher fruit quality than the second season crop, is particularly adequate for scheduling ripening time, hence filling the gaps in product offer by flat-area cultivation during specific periods. Furthermore, mountain cultivation in marginal and low anthropized areas allows production of high quality marketable strawberries. Further comparative tests are needed to study in detail the effect of climate, soil, and especially of the ecological background of mountain areas on strawberry cultivation.

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