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Quality and Antioxidant Properties of Apricot Fruits at Ready-to-Eat: Influence of the Weather Conditions under Mediterranean Coastal Area

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Abstract

The effect of different weather conditions on fruit quality of 'Pisana' apricot cultivar (*Prunus armeniaca* L.) was evaluated over seven consecutive harvesting seasons in central Italy. The main physical-chemical traits, total antioxidant capacity and total phenols of fresh apricots at ready-to-eat were studied. The fruit quality showed a high variability in relation to the climatic conditions, particularly due to the summer rainfall. The most influenced quality parameters were TSS, TA and antioxidant levels: under wet seasons a huge reduction was observed, while strong drought conditions increased these chemical compounds. To improve fruit quality, 'Pisana' cultivar benefits of environmental conditions typical of temperate and semi-temperate regions, where water is usually limited.

Keywords: *Prunus armeniaca* L.; Climatic conditions; Fruits; Physical-chemical traits; Total antioxidants; Total phenols

Introduction

Apricot (*Prunus armeniaca* L.) is a fruit species with a nutritional value of interest having a good source of fiber, minerals (especially potassium but also calcium, iron, magnesium, zinc, phosphorus and selenium) and vitamins such as vitamin A, vitamin C, thiamin, riboflavin, niacin and pantothenic acid [1]. Moreover, apricots contain a number of main secondary metabolites such as polyphenols, carotenoids, fatty acids, volatiles and polysaccharides whose biological activities are considered useful for exerting various biological activities desirable for human health [2]. In particular, phenolic compounds are one of the main sources of antioxidant activity which are able to prevent oxidative stress scavenging free radicals and nitrogen species [3]. Antioxidant properties and quality traits of fruits are strictly related to genetics (species and cultivars) whose are influenced by geographic area, environment and cultivation techniques [4-6]. Climate has an important role on quality, affecting the nutritional value of vegetables and fruits [7]. In particular, light intensity and temperature together with water availability are related to the antioxidant activity in different fruit species [8]. Furthermore the deficit irrigation, as well, influence the phenol content in fruit as reported by several authors [9-11]. In apricot, recent studies showed that the bioactive compounds, such as the antioxidant content, are mainly related to the genotype and pedo-climatic conditions [12]. A screening among several apricot cultivars from international and Italian germplasm revealed some interesting varieties showing a high antioxidant capacity of fruits [13]. In particular, 'Pisana' cultivar stood out for its excellent pomological and antioxidant fruit properties, so as it is also appreciated in non-EU countries such as Latin America [14]. 'Pisana' was patented in Italy by the University of Pisa's breeding programmes and it is characterized by late blooming and ripening time, and strong fruit attractiveness for the fresh market [15,16]. In a two-year experimental trial, it has been showed that some fruit quality traits of 'Pisana', mainly total antioxidant capacity and total phenols, can be influenced by climatic conditions during the fruit growth and ripening [17]. Consequently, more studies about the effect of annual climatic variability on apricot quality are needed. In particular, researches combining environmental conditions, pomological traits and nutraceutical properties of apricot fruits over many years are rare. The aim of this research was to assess the influence of temperature and rainfall on fruit quality of 'Pisana' cultivar, over seven consecutive harvesting seasons. In particular, the effect of these climatic factors on the antioxidant potential of apricot was determined.

Materials and Methods

Plant material

The research was conducted over several harvesting seasons (2005-2012) on full bearing apricot trees of cultivar 'Pisana'. This cultivar i s characterized by late blooming and ripening time, +8 days from 'San Castrese' (last decade of June), reference cultivar for the Italian apricot ripening calendar. Trees, grafted onto Myrabolan 29C rootstock, were grown at the experimental Station of the Department of Agriculture, Food and Environment of Pisa University located in a coastal area of Tuscany (Italy, altitude 6 m a.s.l., lat. 43.02 N, long. 10.36 E). The site is characterized by mild-winters and annual average rainfall is about 600 mm; the soil in orchard is loam, moderately deep, medium texture, slightly alkaline, non-calcareous. Trees, trained to a free palmette system (4 m × 4.5 m) with rows facing east-west, were not irrigated and routine conventional horticultural management (pruning, thinning, fertilization, pest and disease protection) was performed. The experimental design was established in a completely randomized design. The main climatic parameters were acquired. Hourly temperatures were registered by an automatic data-loggers (Tynitag Plus®, West Sussex , UK, 2003) and rainfall data were provided by the Regional Agro-meteorological Service of Florence (ARSIA,

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'Agenzia Regionale per lo Sviluppo e l'Innovazione nel settore Agricolo Forestale' Tuscany, Italy).

Crop entity and physical-chemical fruit parameters

Crop entity and apricot fruit quality were assessed at physiological maturity (ready-to-eat stage). The crop entity average was evaluated on ten trees (kg/tree) and expressed as crop index (CI) related to 5 yield classes: < 1 kg (class 1); 1-5 kg (class 2); 5.1-10 kg (class 3); 10.1-20 kg (class 4); > 20 kg (class 5). Samples of 30 fruits were randomly collected to determine the main physical-chemical parameters, total antioxidant capacity, and total phenol content. From each fruit, measurements of fresh weight, peel and flesh color, pulp firmness, total soluble solids (TSS), and titratable acidity (TA) were determined. The skin color of the un-blushed side was evaluated using a color chart for apricot fruit according to Lichou et al. [1] by 10 shades of growing intensity from 1 (green) to 10 (red-orange) through different categories (1-4: yellow-green; 5-8: yellow-orange; 9-10 red-orange). The skin color of the blushed side ranges from pink to red. The area of the blushes was evaluated visually by classifying the red area according to the following classes: SC-b: < 15% (class 1); 15.1-25% (class2); 25.1-35 (class 3); > 35% (class 4). Firmness (kg 0.5 cm^2) was evaluated with a manual penetrometer (Model 53200SP TR, TR-Turoni & C. Inc Forlì, Italy) on two opposite sides at the equatorial region of the apricot, using an 8-mm-wide plunger. TSS was measured using a refractometer (Model 53015C TR, TR-Turoni & C. Inc Forlì, Italy) and expressed in °Brix at room temperature. TA was determined in fruit juice by titrating known volume of juice with 0.1 N sodium hydroxide (NaOH) to an end point of neutral pH (8.1). TA was expressed as milliequivalents per 100 grams of fresh weight (meq 100 g^{-1} FW).

Antioxidant proprieties

The Total Antioxidant Capacity (TAC) and Total Phenols (TP) analyses were carried out on the same fruits that had been previously subjected to the physical and chemical determinations. Samples of fresh material (3 g, in triplicate), homogenized using an ultra-Turrax T25 (Ika, Staufen, Germany) at 4°C to avoid oxidation, were performed in 80% ethanol for 1 h in a shaker in the dark and subsequently centrifuged at 2600*g* for 10 min at 2-4°C.

TAC assay

Total antioxidant capacity was evaluated using the improved Trolox Equivalent Antioxidant Capacity (TEAC) method [18]. The TEAC value was calculated in relation to the reactivity of Trolox, a water-soluble vitamin E analogue, which was used as an antioxidant standard. In the assay, 40 μl of the diluted samples, controls, or blanks were added to 1960 μl $ABTS^{\bullet +}$ solution, which resulted in a 20-80% inhibit ion of the absorbance. The decrease in absorbance at 734 nm was recorded at 6 min after an initial mixing, and plotted against a dose-response curve calculated for Trolox (0-30 μM). Antioxidant activity was expressed as micromoles of Trolox equivalents per gram of fresh fruit weight (μmolTE g^{-1} FW). Trolox was purchased from Sigma Chemical Co. (St. Louis, MO, USA).

TP assay

Total phenolic content was determined according to the improved Folin- Ciocalteu (F-C) method [19]. The assay provides a rapid and useful indication of the antioxidant status of the studied material and has been widely applied to different food samples. Gallic acid (GA; Sigma Chemical Co., St. Louis, MO, USA) was used as a standard compound for the calibration curve. Total phenol content was calculated as milligrams of GA equivalent (GAE) per gram of fresh fruit weight (mgGAE g^{-1} FW). The absorbance of the blue colored solutions was read at 765 nm after incubation for 2 h at room temperature.

Statistical Analysis

Data, reported as means ± standard errors (SEM), were analyzed by one-way analysis of variance (ANOVA), and differences were considered statistically significant at $p \leq 0.05$ according to Tukey test. Pearson's correlation and regression analysis were performed in order to determine relationships between pomological and antioxidant properties, cumulative rainfall and TAC-TP levels, respectively.

Results

Climatic conditions

Average monthly maximum and minimum temperatures and the amount of rainfall from March to June, over a 7-year period (2005-2012), are shown in Figures 1 and 2. During the final stages of fruit growth, the average (AVG) of minimum and maximum temperatures in the last years have been 13.5-24.2°C (May) and 16.2-26°C (June), respectively. In particular, 2007 and 2009 showed the highest maximum temperatures, 3-4°C more than to the AVG of the considered climatic area; as a consequence, the highest max-minimum temperature fluctuations occurred. These two years were also characterized by rainy spring-early summer seasons and the cumulative precipitations were unusually high (380 mm in 2007 and 420 mm in 2009), against the average value of the last ten year period (155 mm); both years recorded rainfalls over May and June. The driest year was 2006, when the cumulative rainfall was only 65 mm, mainly occurred in March; this year was also characterized by minimum temperatures higher than the AVG.

Physical-chemical fruit parameters

The main pomological traits of fruits are reported in Table 1. Among the tested years, the average of fruit size by weight was about 72 g, differing from 65.2 g (2006) to 82.9 g (2009), independently from the crop index which was similar in these years (class 2). Considering the physical traits of fruit, the skin color of the un-blushed side was yellow-orange (7-8 intensity) and the area of the blushes was between class 2 and 3, denoting a moderate cover color, always below 35% over the years. Fruit flesh firmness, TSS and TA showed significant variations among years. Flesh firmness varied from 1.7 kg 0.5 cm^{-2} (2011) to 2.9 kg 0.5 cm^{-2} (2009); soluble sugars (TSS) ranged from 11.9 °Brix in 2009 to 16.3 °Brix in 2006, the wettest and driest years, respectively. TA values changed between 9.0 meq 100 g^{-1} FW in 2011 and 17.3 meq 100 g^{1} FW in the wettest year 2009. As a consequence, the TSS/TA ratio changed and it was particularly low (0.8 and 0.7) in the wettest years 2007 and 2009.

Antioxidant proprieties

A significant years's effect was observed on the on the antioxidant levels. The total antioxidant capacity (TAC) ranged from 2.69 to 9.01 μmolTE g^{-1} FW (Figure 3A). In the wettest years (2007 and 2009) the lowest values were recorded, while in the years 2006, 2011 and 2012, values were 3-fold higher than 2007 and 2009. Total phenol content (TP), similar to TAC, showed a significant variability related to the years, and values ranged from 0.55 to 1.53 mgGAEg^{-1} FW (Figure 3B); the lowest and the highest values were recorded in the wettest and driest years, respectively. A high correlation was found between antioxidant proprieties (TAC and TP) and rainfall occurred during the spring-early

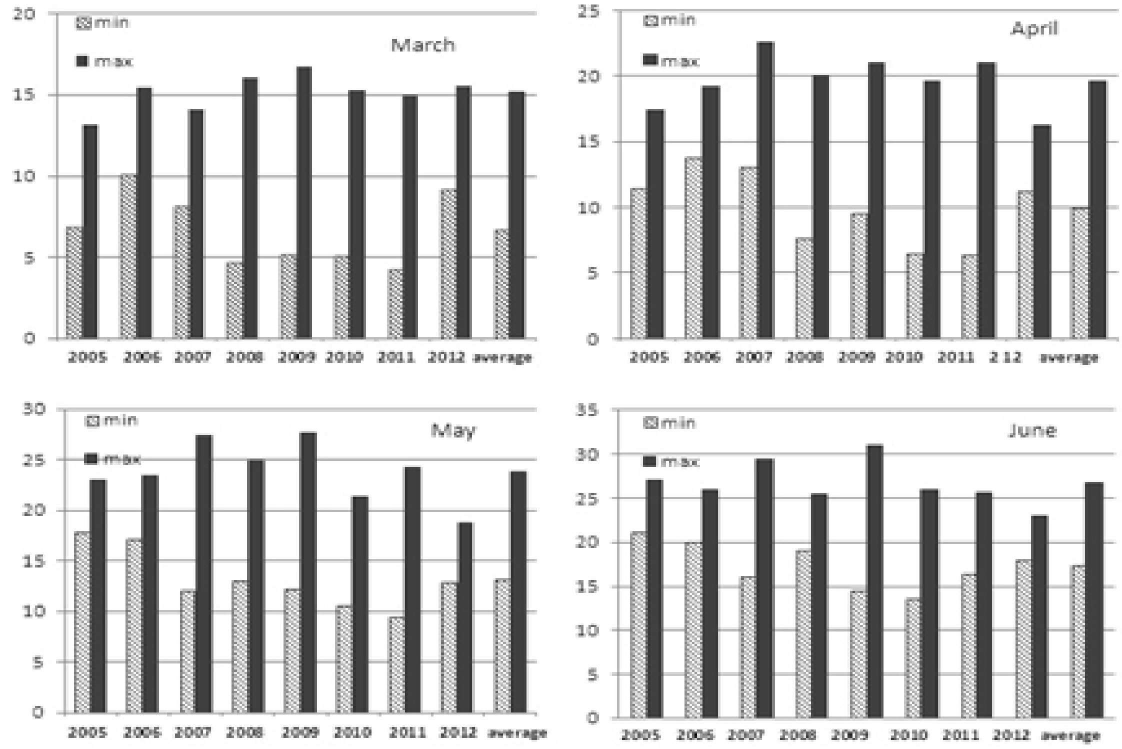

Figure 1: Average monthly minimum and maximum temperatures (°C) from March to June (2005-2012). The relative average of years is also showed

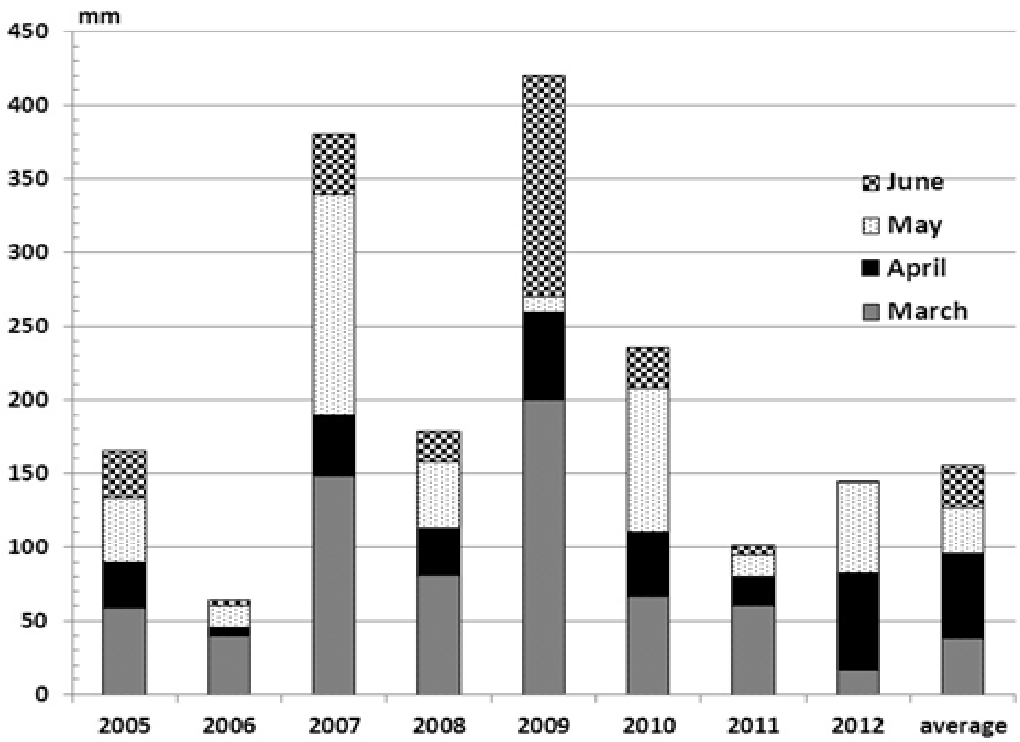

Figure 2: Cumulative monthly rainfall (mm) from March to June (2005-2012).

Year	C.I	F.W.	SC-b	F.F	TSS	TA	TSS/TA
2005	3	71.4 ± 3.6ab	2	2.5 ± 0.4ab	16.3 ± 0.6c	10.5 ± 0.2a	1.5
2006	2	65.2 ± 4.0a	3	2.7 ± 0.3ab	16.1 ± 0.4c	14.4 ± 0.6b	1.1
2007	4	69.0 ± 1.7ab	2	1.6 ± 0.1a	13.1 ± 0.5ab	15.6 ± 0.3b	0.8
2009	2	82.9 ± 3.8b	2	2.9 ± 2.0b	11.9 ± 0.4a	17.3 ± 0.6b	0.7
2010	3	73.8 ± 3.6ab	2	2.8 ± 0.4b	12.2 ± 0.6a	11.0 ± 0.4a	1.1
2011	4	72.8 ± 3.4ab	2	1.7 ± 0.1a	14.9 ± 0.3bc	9.0 ± 0.2a	1.6
2012	2	69 ± 1.9ab	2	2.4 ± 0.2a	15.9 ± 0.6bc	16.4 ± 0.3b	1
Avg	2.9	72.1 ± 1 0.2	3.2	2.4 ± 0.1	14.4 ± 0.6	13.1	1.1

Table 1: Main physical-chemical traits from apricots, cv 'Pisana', recorded over a 7-year period: C.I. (crop index, kg/tree), F.W. (fruit weight, g), SC-b (skin colour of the blushed side), F.F. (flesh firmness, kg 0.5 cm^{-2}), TSS (total soluble sugars, °Brix), T.A. (titratable acidity, meq 100 g^{-1} FW), TSS/TA (sugars/acids ratio). Mean ± standard error. Means within the same column followed by the same letter, do not differ significantly according to Tukey test at $p \leq 0.05$.

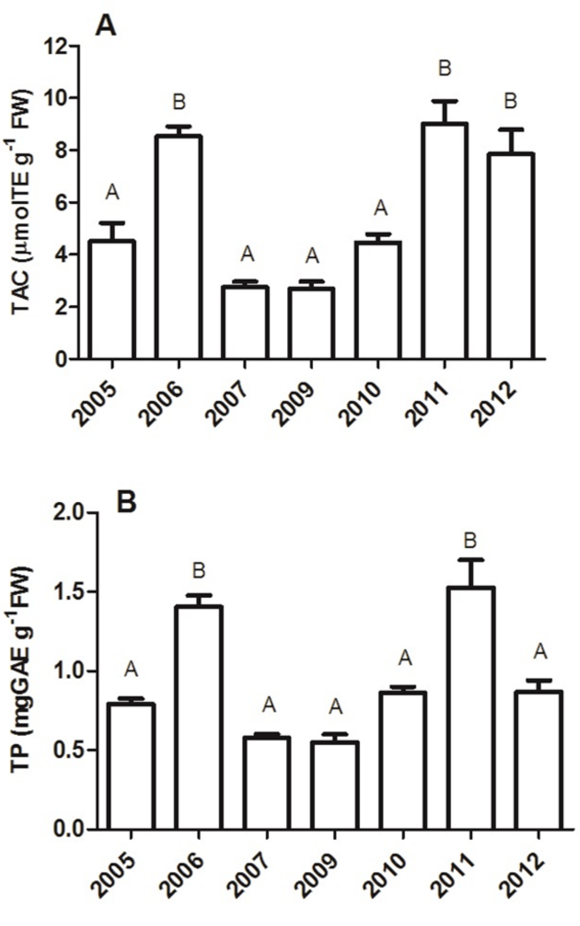

Figure 3: (A) Total Antioxidant Capacity (TAC) and (B) Total Phenols (TP) in apricots of 'Pisana' cultivar recorded over a 7-year period. Values are means ± standard error. Means with different letters are significantly different (p≤0.01) according to Tukey's test.

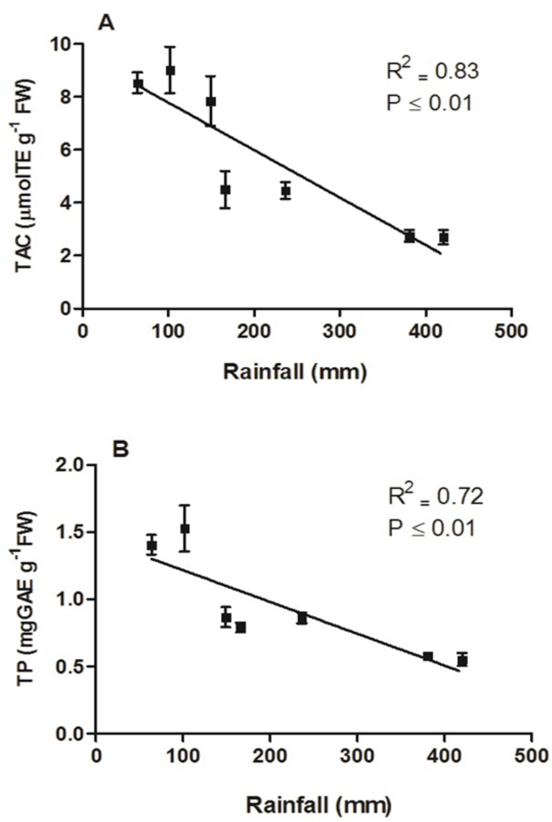

Figure 4: Linear regression between TAC (A), TP (B) and cumulative monthly rainfall (mm) from March to June over a 7-year period. Means ± standard error.

summer seasons (Figures 4A,4B). The correlation coefficient was 0.83 for TAC and 0.72 for TP.

Discussion

The main quality traits of 'Pisana' apricots at ready-to-eat were characterized by fluctuations in relation to the studied years. However, the average physical-chemical data were similar to those recorded in previous researches; TAC and TP levels were inside the interval of 'Pisana' which define this cultivar with a good antioxidant power, when compared to a wide number of commercial apricot genotypes [20]. In Table 2 are reported the Pearson's coefficients among different fruit pomological and chemical properties to find out possible relations between pomological traits and antioxidants. The results over a 7-year period showed a general negative correlation between fruit weight and firmness with chemical parameters, such as sugar content, total antioxidant capacity and total phenols. A weak relation between TSS and TA was observed, not fully in agreement with other researches where these parameters were well linked, denoting them

	FW (g)	Firmness (kg0.5cm²)	TSS (°Brix)	TA (meq100g⁻¹ FW)	TSS/TA	TAC (μmolTEg⁻¹ FW)	TP (mgGAEg⁻¹ FW)
FW	1						
Firmness	0.121	1					
TSS	-0.621	-0.459	1				
TA	0.165	0.622	0.092	1			
TSS/TA	-0.314	**-0.805**	0.173	**-0.903**	1		
TAC	-0.51	-0.751	**0.873**	-0.341	0.576	1	
TP	-0.393	-0.7	0.656	-0.555	0.649	**0.877**	1

Table 2: Pearson's coefficients among fruit weight (FW), flesh firmness, total soluble sugar (TSS), tritatable acidity (TA), sugar/acid ratio (TSS/TA), total antioxidant capacity (TAC) and total phenols (TP) for 'Pisana' cultivar over a 7-year period. Bold coefficients are significant at $p \leq 0.05$.

as determinant to define the fruit gustative quality [21]. Positive correlation coefficient was found between TAC and TP (r = 0.877), which confirms a significant contribution of polyphenols to the total antioxidant capacity as reported for several fruit species and apricot too [4,12,22,23]. TAC was also significantly correlated with TSS (r = 0.873).

During the considered 7-year period, the final stage of fruit growth in 2006, 2007 and 2009 was characterized by climatic conditions which differed from the average of the last years. In May and June of 2007 and 2009 years, high temperatures associated to unusual and heavy rainfall events occurred; on the other hand, the year 2006 was particularly warm and dry. These climatic disorders determined an anomalous microclimate which also differed from the seasonal averages of the past 20 years for the same cultivation area [24]. During the growth-ripening period, the different weather conditions strongly influenced the quality parameters of fruits. In the warm-wet 2007 and 2009 years, 'Pisana' apricots showed the lowest TSS , highest TA and a consequent very low TSS/TA ratio, key parameters related to the eating quality for consumer preference [25,26]. These traits were markedly modified in the dry year (2006) which led to a smaller fruit size characterized by a TSS increase, and a TA decrease with a more balanced TSS/TA ratio. Analogous results were also obtained by several authors, confirming the positive influence of dry conditions on apricot quality traits during the intensive ripening period [27,28]. In particular, the accumulation of sugars in fruit, by conversion of starch, can be enhanced by water stress as a result of reduced irrigation [29-32]. In spite of this, the different climatic conditions had little effect on other physical quality attributes, such as the cover color, confirming this trait as genetic imprint of a genotype [33]. On the other hand, climatic conditions strongly influenced the antioxidant proprieties expressed by TAC and TP values, which markedly changed among the analyzed years. A linear significant inverse relationship between cumulative monthly rainfall and TAC-TP levels was found (Figure 4): in the years characterized by high rainfalls and concomitant warm temperatures, fruits had the lowest antioxidant levels, while in the driest year they reached the highest TAC and TP values. These results are in accordance with recent works showing the key role of water availability on fruit quality traits. These investigations, involving pomological properties, phenolic composition and volatile compounds of different species, have found an inverse relationship between water status and antioxidant content [10,11]. In apricot, a relationship between antioxidant levels and drought conditions was found comparing the autochthonous cultivar 'San Castrese' under different growing sites [34]. Moreover, variability between harvest seasons and antioxidant values was recently found in several apricot genotypes [20]. A number of experimental researches have been addressed on the application of regulated deficit irrigation as a strategy to be applied in areas where water resources are limited. It has been found that deficit irrigation during the fruit growth period might have a positive effect on fruit quality by improving taste, associated with an increase in soluble solids content [27,35,36]. For certain fruit species, such as pomegranate, this agronomical practice is considered as determinant to enhance fruit composition and postharvest performance [11]. Alternatively, excessive watering may have adverse effects on fruit quality, since it increases tree vegetative growth, which promotes a nutritional imbalance and decreases fruit dry mass [37].

Conclusions

From the results presented in this study, 'Pisana' cultivar confirmed to have an excellent fruit qualitative profile which combines good source of antioxidant compounds and pomological traits. These appeals could drive this cultivar as possible genetic source for breeding programs addressed to produce new genotypes which associate the best agronomic performance to fruit quality traits. The analysis carried out over seven consecutive harvesting seasons allowed establishing that fruit quality showed a high variability in relation to the climatic conditions, particularly due to summer rainfall. The most influenced quality parameters were TSS, TA and antioxidant levels as a physiological response to abiotic stresses; under wet seasons a huge reduction was observed, while strong drought conditions increased these chemical compounds. From the agronomical point of view, to improve fruit quality, 'Pisana' cultivar benefits of environmental conditions typical of temperate and semi-temperate regions where water is usually limited, which seems to be a condition able to enhance the antioxidant level whose importance is strictly related to human health.

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