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Cropping system contributes largely to fruit composition and sensory properties of pomegranate (*Punica granatum* L. var. Gabsi)

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A B S T R A C T

The oasis, where pomegranate is grown simultaneously with several crops, is considered as an ecosystem with particular properties. No research has been made to investigate the relationship between pomegranate fruit quality and oasis environment. A comparison between full shade oasis (pomegranate trees were intercropped with date palm trees and other fruit species), partial shade oasis (pomegranate trees grown under date palm trees) and regular orchards with full sun conditions has been investigated in terms of fruit quality. The full shade oasis microclimate was more favourable to obtain pomegranate arils with an attractive red colour and high total anthocyanin content. Pomegranates under these conditions contained total volatile content (79–144 μg L^{-1}) which was about 2 times higher than that in full sun exposed fruits (47–64 μg L^{-1}). Particularly, hexanal and limonene were the most abundant compounds characterizing the aroma profile of fruits cultivated under full shade oasis, and their arils were the most appreciated in terms of colour, odour and taste by Tunisian consumers. However, fruits from partial shade oasis provided the sweetest juices with high concentrations of glucose (59.8–63.3 g L^{-1}) and fructose (108–111 g L^{-1}). Titratable acidity and total organic acids content were also higher in fruits grown under Zarat 3 characterized by partial shade conditions. PCA analysis was used to identify which physicochemical and sensory attributes were more closely linked to oasis conditions. Red colour intensity, monoterpenes, hexanal, citric and quinic acids were useful to discriminate full shade oasis. These compounds seem to contribute to the typical organoleptic properties of oasis pomegranate fruits.

1. Introduction

Pomegranate (*Punica granatum* L.) belongs to the Lythraceae family and has been a culturally important plant in northern Africa since ancient times. This fruit tree can be grown in a wide range of climates from temperate to desert conditions. In recent years, pomegranate has gained popularity due to its multi-functionality and nutritional value in human diet (Calin-Sanchez et al., 2011).

Tunisia is one of the main producers of pomegranate in the Mediterranean countries with a total production of 83,000 tons in 2016. Gabès oasis being a major pomegranate producing area in terms of acreage and production as it gives 40% of total production (G.I.Fruits, 2016). Considered as an ≪Outstanding Universal Value≫, Gabès oasis is one of the last of its kind in the world (UNESCO, 2010; Verner, 2013). The area is considered unique because of its rich wildlife and fauna, breath-taking landscape and its complex traditional irrigation system. The pomegranate species is considered a major component of this oasis and Gabsi is the dominant variety.

The oasis is an intercropping system which was one of the most effective human adaptation strategies in an environment challenged by pronounced temperature variations and low precipitation (Cheneval, 2016). Typically, the oasis is based on the date palm grove, essential element for creating its microclimate that allows the cultivation of other fruit trees (pomegranate, fig, citrus, etc.), forage crops and vegetables forming the lower storey (Sellami and Sifaoui, 1998). In arid regions, because of high temperature and drought, the oasis effect, is defined as "the vegetation cooling effect" due to extensive evapotranspiration in oasis compared with the surroundings (Hao et al., 2016). According to Riou (1990), three elements are modified in the presence of the oasis; water content in the upper soil layers is higher, the dynamic roughness (or the friction force of the wind) increases by the presence of trees and several levels of vegetation and the vertical distribution of the radiant energy is dispersed in the oasis according to plant strata. These findings were later confirmed by Potchter et al. (2008). Light partitioning between intercrop components is a main determinant of their transpiration and photosynthetic capacity, hence water

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consumption and biomass production (Sellami and Sifaoui, 2008). Moreover, dense foliage and multiple layers of canopy can partially or totally obstruct incoming radiation, resulting in cooler temperatures at the shaded side (Middel et al., 2014). Studies showed that summer air temperature of oasis can be cooler 2–7 °C while relative humidity measurements in oasis was up to 6% than their surroundings in desert environments (Saaroni et al., 2004).

Few studies related to the effects of environmental factors on pomegranate fruit quality have been carried out (Mirdehghan and Rahemi, 2007; Schwartz et al., 2009), and even less have focused on the effect of climate on sensory and nutritional traits, whereas it is necessary to take these factors into account to improve final pomegranate quality. Hence, this study was undertaken to investigate the impact of oasis cropping system on physicochemical and sensory properties of pomegranate fruit, cv. Gabsi, compared with those grown in new regular orchards under full sun exposure.

2. Materials and methods

2.1. Plant material

The study was carried out in Gabès 'South-East of Tunisia'. This region is characterized by an arid climate with mild winter and hot summer on the coast. The sampling was done from different trees of commercial "Gabsi" variety. *Punica granatum* var. "Gabsi" is a local pomegranate variety which takes its denomination from its geographic origin (Gabès). Generally, "Gabsi" is a mid-early maturing variety producing mature fruits from approximately mid-September in southern Tunisia. This variety bears big-sized fruits with relatively large calyx and spreading outward sepals. When fully mature, 'Gabsi' fruits are reddish with yellowish blush. They contain many moderately soft seeds enclosed in a red juicy edible pulp which is sweet and slightly acid (Mars and Gaaliche, 1993; Mars and Marrakchi, 1999). Fruit samples were obtained at the commercial harvest date from eight orchards located at four localities: Zarat (33° 40′ 00″ N, 10° 21′ 0″ E), Kettana (33° 46′ 00″ N, 10° 12′ 00″ E) and Zerkine (33° 45′ 00″ N, 10° 17′ 00″ E) in Southern Gabès, whereas Ouedhref (33° 59′ 00″ N, 95° 58′ 00″ E) in Northern Gabès. In three orchards (Kettana 1, Kettana 2 and Ouedhref), pomegranate trees were cultivated in an oasis system. Several fruit species such as olive trees, grapes and citrus were planted, under date palms, in combination with pomegranate trees. In such intercropping system (oasis conditions), pomegranate fruits were grown in full-shade conditions. The orchards of Zarat 1, Zarat 2 and Zarat 3 were cultivated also in oasis system. However, pomegranate trees were intercropped only with date palm trees. These conditions make fruits in partial shade. In Zerkine 1 and Zerkine 2, pomegranate trees were grown in full sunlight conditions since trees were planted without intercropping.

2.2. Sampling and sample processing

From each orchard, ripe fruits from 5 different sites of each canopy of 5 trees were harvested at the beginning of October at early morning during the coolest time (medium temperature and moderate humidity) and immediately transported to the laboratory. Fruits were manually peeled and juice was obtained from fleshly arils using a domestic blender and filtered through a cloth tissue. Juice was stored at −20 °C for further analysis.

2.3. Physicochemical analysis

Titratable acidity (TA), pH, total soluble solids (TSS) and maturity index (MI) were evaluated as quality indexes. Juice pH was measured using a pH-meter (Jenway). The TA was determined by acid–base potentiometry (0.1 mol L^{-1} NaOH up to pH 8.1), expressed as g L^{-1}. The TSS content was recorded using a refractometer (Atago) at 20 °C with values being expressed as °Brix. Aril colour of each fruit placed in a colourless glass petri dish, was measured in CIE$L^*a^*b^*$ coordinates (L^*, a^*, b^*) using a Minolta Chroma Meter CR-400 (Minolta Corp, Osaka, Japan) after calibration with white tile background. All analyses were repeated twenty times and results were expressed as means ± SE (standard error).

2.4. Total anthocyanin content

Total anthocyanin content (TAC) was determined according to the pH differential method (Cheng and Breen, 1991). Briefly, 0.4 mL of pomegranate juice was diluted in 3.6 mL of two different buffers: potassium chloride (0.025 M, pH 1.0) and sodium acetate (0.4 M, pH 4.5). The absorbance (A) of two dilutions was measured at 510 and 700 nm, where $A = (A_{510\ nm} - A_{700\ nm})_{pH\ 1.0} - (A_{510\ nm} - A_{700\ nm})_{pH\ 4.5}$. The content of total anthocyanins (mg cyanidin-3-glucoside/L) was calculated as: $TAC = (A \times MW \times DF \times 1000) / (\varepsilon \times l)$, with an extinction coefficient (ε) of 26,900 L mol^{-1} cm^{-1} and molecular weight (MW) of 449.2 g mol^{-1}.

2.5. Analysis of organic acids and sugars

Organic acids and sugars were quantified according to Carbonell-Barrachina et al. (2012). Briefly, 1 mL of centrifuged juice (10,000 ×*g* for 20 min) was passed through a 0.45 μm Millipore filter and then injected into a Hewlett-Packard Series 1100 (Wilmington, Del, USA) high-performance liquid chromatography (HPLC). Organic acids were isolated and were measured using a diode array detector (DAD) set-up at 210 nm. For sugar analyses, the detection was conducted using a refractive index detector (RID). Sugars and organic acids were determined in triplicate and results were expressed as g L^{-1}.

2.6. Volatile compounds

2.6.1. Extraction procedure

Volatile compounds were extracted from pomegranate juices using headspace solid phase micro-extraction (HS-SPME) as described by Calin-Sanchez et al. (2011). After several preliminary tests to optimize the extraction system, 15 mL of juice was hermetically placed into a 50 mL vial with a polypropylene cap and a polytétrafluoroéthylène (PTFE)/silicone septum. 1 μL of the internal standard (benzyl acetate) was added together with NaCl and the vial was equilibrated for 15 min at 40 °C in the water bath. Then a 50/30 μm Divinylbenzene/Carboxen/Polydimethylsiloxane (DVB/CAR/PDMS) fibre was exposed to the sample headspace for 50 min at 40 °C.

2.6.2. Chromatographic analysis

Isolation and identification of the volatile compounds were performed using a Shimadzu GC-17A gas chromatograph coupled with a Shimadzu QP-5050A mass spectrometer (Shimadzu Corporation, Kyoto, Japan). The GC/MS system was equipped with a TRACSIL Meta.X5 column (95% dimethylpolysiloxane/5% diphenylpolysiloxane, 60 m × 0.25 mm, 0.25 μm film thickness; Teknokroma S. Coop. C. Ltd., Barcelona, Spain).

The volatile studies were conducted in triplicate. The concentration of each compound is expressed as % of the total arbitrary area units.

2.7. Descriptive sensory evaluation

Eight highly trained panellists, (aged 23 to 51 years; 50% females) from the research group "Food Quality and Safety" of the Miguel Hernández University (UMH, Orihuela, Alicante, Spain) participated in the study. The panel was selected and trained following the ISO standard 8586 (2012), and it is specialized in descriptive sensory evaluation of fruits and vegetables, including pomegranate products (e.g. Szychowski et al., 2015). For the current study, no orientation session was needed, because of the high expertise of the panel on