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Physico-chemical changes during growth of persimmon fruits in the East Mediterranean climate region

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Physico-chemical changes were monitored during growth of pollination variant non-astringent 'Harbiye' persimmon fruits (*Diospyros kaki* L.) grown at low or high altitude of the East Mediterranean Region of Turkey for two growing seasons (2001–2002 and 2002–2003). Fruit growth in diameter followed a typical double sigmoid curve, consisting of two rapid growth stages, stage I and stage III, separated by a period of slow growth (stage II) at both altitudes. The durations of stages I, II and III were 105–119, 21–35 and 21–42 days, respectively, at low and high altitude. 'Harbiye' persimmons showed significant decreases in soluble tannin concentration and total carotenoid content during stage I. At the end of stage I, 'Harbiye' persimmons became non-astringent. Stage II was characterized with slow growth, the beginning of acid degradation and a significant increase in total sugars, especially in the sucrose component. At end of stage II, the fruit began to turn yellow-orange, indicating the occurrence of colour break. The greatest increase in total soluble solids (TSS) content occurred in the final month before harvest during stage III when pronounced changes in skin colour and softening of fruits were observed. The 175 and 168 days after full bloom (DAFB) at low and high altitudes, respectively, are appropriate timing for harvest of the 'Harbiye' persimmon fruits in the East Mediterranean region. At these stages, 'Harbiye' persimmon fruits reached the best quality for consumers.

1. Introduction

Recent expansion of persimmon cultivation is mostly in temperate and subtropical regions outside the major production areas (Mowat et al., 1995). The persimmon industry in Turkey has been expanding due to domestic demand and export market opportunities for persimmon fruits. In, Turkey, the main producer areas are located on the eastern part of the Mediterranean Region where production is concentrated in two distinct regions: low lands and high lands.

Climatic differences between persimmon growing regions cause a wide variation in persimmon fruit growth, maturity and quality at harvest (Mowat et al., 1997). Persimmon fruits have been shown to follow a double sigmoid growth curve, consisting of two rapid growth stages, stage I and stage III, separated by a period of slow growth (stage II) (Zheng et al., 1990; Sugiura et al., 1991). However, persimmon fruit growth has not been analyzed with fitting curves. Fitting curves allow for the calculation of absolute and relative growth rates and thus permit prediction and forecasting of fruit size, and also identification of the time of critical stages (Godoy et al., 2008) in order to optimize crop management and avoid inconsistent fruit quality in the domestic and export market.

The physical and chemical characteristics of persimmon fruits are important in assessing fruit quality and identifying correlations between changes in these characteristics, making quality control easier. Various quality characteristics of persimmon cultivars including chemical composition, physical characteristics and volatile compounds have been studied (Taira, 1996; Senter et al., 1991). Forbus et al. (1991) related physical and chemical changes to maturation stages of persimmons. Maturity is important for the quality of any fresh fruit, and the ability to measure its accuracy is essential for efficient marketing and consumer satisfaction. Various maturity indices of changes in physical and chemical properties have been used to monitor fruit growth so that appropriate harvest dates for a given fruit can be determined. However, there are limited studies on physical and chemical characteristics of persimmon cultivars grown in the Mediterranean Region. Some correlations between the physical and chemical parameters are not yet fully identified in this region.

The aim of this study was to analyze fruit growth, to determine the effects of altitude on fruit growth and maturity by monitoring

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physical and chemical characteristics during fruit growth and to evaluate the relationship between the characteristics that relate to maturity in order to determine optimum harvest time of PVNA persimmon fruits grown at low and high altitudes in the East Mediterranean Region.

2. Materials and methods

The experiment was carried out in 5–6-year-old commercial PVNA 'Harbiye' persimmon orchards located in Belen, Hatay (high altitude 770 m from see level, 36°26′29″N and 36°10′01″E) and Antakya, Hatay (low altitude 229 m from sea level, 36°08′29‴N and 36°08′28″E) during the 2001–2002 and 2002–2003 seasons in the East Mediterranean Region of Turkey. These locations represent the major production areas in this region and have typical Mediterranean climate conditions with hot-dry summers and mild-rainy winters. Monthly day and night temperatures were obtained from the agro-meteorological station nearby the persimmon orchards at low and high altitude during the 2002 and 2003 season (Table 1).

Full bloom occurred April 24–30 in low altitude and May 1–7 in high altitude in 2003 and 2002, respectively. Five trees grafted on *Diospyros lotus* L. at both locations were tagged to follow fruit growth. Fruit diameter was measured on 50 randomly selected fruits from each of five replicate trees using digital calipers from the beginning of July to the end of October at 15-day intervals. Ten fruits from each tree were also collected on each sampling day to determine changes in skin colour, flesh firmness, total soluble solids (TSS) content and titratable acidity (TA). Skin colour was determined with a Minolta Chroma Meter CR-300 (Osaka, Japan). Colour measurements were recorded using the CIE $L^*a^*b^*$ colour space. From these values, hue angle was calculated as $h° = \tan -1\ (b^*/a^*)$. Colour values for each fruit were computed as means of two measurements taken from opposite sides at the equatorial region of the fruit. Flesh firmness was measured on two opposite sides of each fruit at the equatorial region, after the removal of a 1 mm thick disk of skin from each side of the fruit, and the force in kg required to insert an effegi penetrometer (Model FT 327) fitted with an 8 mm diameter probe was recorded and converted to Newtons (N). TSS content and TA were assessed in juice obtained from ten fruits per replicate. TSS content was determined with a refractometer (Atago Model ATC-1E) and TA by titration of 5 ml of fruit juice with 0.1 N NaOH to pH 8.1, and it was expressed as g malic acid 100 ml^{-1} juice.

Sugar content (sucrose, glucose, and fructose) was determined according to the procedure described by Glew et al. (2005). HPLC analyses of sugars were performed on LC-10A equipment consisting of LC-10AD pumps, in-line degasser, a CTO-10A column oven, a SCL-10A system controller, and a refractive index detector, and operated by LC solution software (Shimadzu, Japan). Sugars were separated on EC 250/4 NUCLEOSIL® Carbohydrate columns (Macherey-Nagel, Düren, Germany) at 25 °C. The mobile phase was acetonitrile: water (80:20, v/v) at a flow rate of 2 ml min^{-1}. The sugars were detected using a refractive index detector and quantified by the external standard method. The results were expressed as a fresh weight (FW) basis (g 100 g^{-1} FW). Total sugar concentration was calculated by adding the concentrations of glucose, fructose, and sucrose. The soluble tannins were measured by the Folin–Denis method (Taira, 1996) and expressed as tannic acid on a FW basis. Total carotenoid content was determined spectrophotometrically using a UV1208 spectrophotometer (Shimadzu, Japan) according to the procedure described by Forbus et al. (1991). The total carotenoid content was measured in terms of β-carotene. The concentration of β-carotene was calculated from a β-carotene standard curve with authentic standard (Sigma–Aldrich Co., Germany) and expressed as μg 100 g^{-1} FW.

Data were subjected to the analysis of variance using GLM procedure of SAS software of SAS Institute, Cary, NC (SAS, 1999) as a completely randomized design with 5 replicates (5 trees). Means procedure of SAS was used to calculate the mean and its respective standard error for each altitude and years.

3. Curve fitting and statistical analysis

Persimmon fruit typically shows a double sigmoid growth curve, consisting of two stages of rapid growth (stage I and stage III) separated by a period of slow growth (stage II) (Zheng et al., 1990; Sugiura et al., 1991). A two-growth-curve model was used to describe the cumulative fruit growth in diameter as suggested by Genard and Bruchou (1993) in peaches. The first model describes the growth during the first rapid-growth period (stage I) and is represented by a monomolecular function, and the second model describes the growth during the second rapid-growth period (stage III) and is represented by a logistic function. Stage II corresponds to the overlapping of the two growth curves. The complete model is

$$y = [p_1^*(1 - p_0^* \exp(-p_2^* t))] + \left[\frac{p_3 - p_1}{1 + \exp(-p_4^*(t - p_5))}\right] \quad (1)$$

where y is the fruit diameter at time of t days; t is the time expressed as days after full bloom (DAFB); p_0 is the scaling parameter; p_1 (mm) is cumulative growth during the first period (stage I); p_2 (day^{-1}) is the relative growth rate at the beginning; p_3 (mm) is cumulative growth for second period (stage III); p_4 (day^{-1}) is proportional to the relative growth rate at p_5 (day), which is the date of maximal absolute growth rate (AGR) during second period (stage III).

First, the data were fit to a linear regression using Eqs. (2) and (3) by the REG procedure of SAS to determine the initial values of estimated parameters of p_0, p_2, p_4 and p_5 for optimization of the NLIN procedure. For p_1 and p_3, the values were chosen larger than the upper diameter observed during the first and second periods

Table 1
Changes in day and night temperatures at low and high altitude in the East Mediterranean Region during 2002 and 2003.

Year	Location	Temperature (°C)	Months						
			April	May	June	July	August	September	October
2002	High altitude	Day	32.0	31.5	31.4	32.8	38.5	33.9	31.6
		Night	3.9	10.8	15.9	18.1	20.9	14.2	9.7
	Low altitude	Day	34.5	34.6	31.4	40.0	42.3	38.0	34.7
		Night	6.2	11.8	18.0	22.0	23.0	15.8	9.8
2003	High altitude	Day	30.0	32.5	29.9	32.0	37.0	35.1	35.0
		Night	5.8	8.5	15.0	19.8	17.3	14.0	9.7
	Low altitude	Day	33.3	36.9	31.0	34.0	40.2	38.4	39.0
		Night	8.0	13.6	19.8	23.2	23.0	15.8	10.4