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

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ABSTRACT

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.

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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 $h^\circ = \tan -1\,(b^*/a^*)$. 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

for each altitude and year:

$$\ln\left[\left(\frac{p_1}{y}\right)-1\right]=b_0+b_1x \quad (2)$$

where b_0 (intercept) is the initial value of p_0 and b_1 (slope) is the initial value of p_2:

$$\ln\left[\left(\frac{p_3}{y}\right)-1\right]=a_0+a_1x \quad (3)$$

where a_1 (slope) is the initial value of p_4, a_0 (intercept) and $-\log a_0/a_1$ is the initial value of p_5.

Then, the growth curve (Eq. (1)) was fitted by the non-linear regression NLIN procedure of SAS using the Levenberg–Marquardt algorithm. The model was fitted to individual data for each location (low and high altitude) and year (2002 and 2003). The goodness-of-fit of the model was evaluated using the Pseudo-R^2 value (Schabenberger et al., 1999) for each location and year. Pseudo-R^2 was calculated using Eq. (4):

$$\text{Pseudo-}R^2=1-\frac{\text{the residual sum square}}{\text{corrected total sum square}} \quad (4)$$

The effect of altitude and season on fruit growth was also tested according to Peek et al. (2002). The nonlinear mixed procedure of SAS was used to fit a model to fruit diameter data from each altitude and year, which had a dummy variable for altitude and year. For parameter p_5, the following nonlinear mixed model applied to the data (Wolfinger, 1999):

$$y_{ij}=[p_1^*(1-p_0^*\exp(-p_2^*t_{ij}))]+\left[\frac{p_3-p_1}{1+\exp(-p_4^*(t_{ij}-(p_5+u_{i1})))}\right]+e_{ij} \quad (5)$$

where y_{ij} represents the jth measurement on the ith treatment; t_{ij} is the days after full bloom; p_0, p_1, p_2, p_3, and p_4 are the fixed-effects parameters described in Eq. (1); u_{i1} are the random-effect parameters assumed to be iid $N(0,\sigma^2u)$, and e_{ij} are the residual errors assumed to be iid $N(0,\sigma^2e)$ and independent of the u_{i1}.

Other parameters were treated the same way. Initial estimates of parameters were obtained using the NLIN procedure. The estimates of all parameters along with the estimated covariance matrix from the NLMIXED procedure were used to compare altitudes and/or years for each parameter by Wald's test according to Peek et al. (2002).

The first derivative or absolute growth rate and the second derivative or absolute growth acceleration (Zeide, 1993) were obtained from each fitted model. Minima and maxima were obtained by numerical computation with the Graphmatica 1.60d software (Ksoft, 2008). Boundaries of each growth stage were determined from local minimum and maximum in the double-sigmoid second derivative. The time between the first minimum and the second maximum of the second derivative was used for the definition of stage II (Godoy et al., 2008).

4. Results

4.1. Fruit diameter

Fruit diameter curves followed a double sigmoid growth pattern, consisting of two rapid growth stages, stage I and stage III, separated by a period of slow growth (stage II). A two-growth-curve model comprising of monomolecular function and logistic function fitted well the cumulative fruit growth in diameter (Fig. 1A) in both altitudes and years ($r^2 \geq 0.99$). Parameter estimates of the model for both altitudes and years are shown in Table 2. The parameters for each altitude and year were significant ($P < 0.05$). The date of maximal absolute growth rate

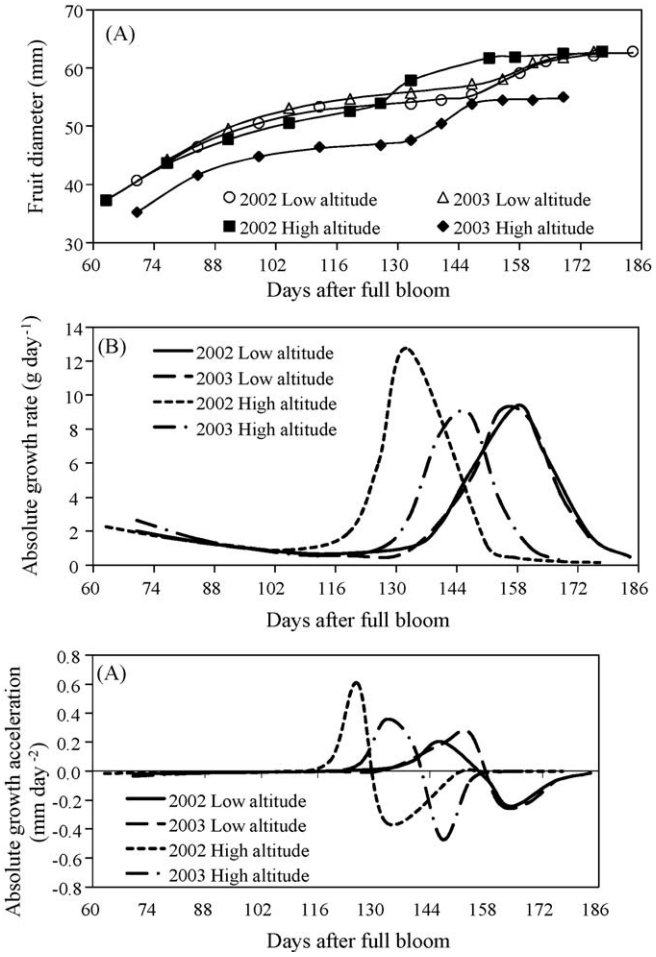


Fig. 1. Observed (symbols) and predicted (lines) cumulative fruit growth in diameter (A), absolute growth rate (B) and absolute growth acceleration (C) of pollination variant non-astringent 'Harbiye' persimmon fruits at low and high altitude in the East Mediterranean Region during 2002 and 2003. Each point represents the mean of five replicates (trees).

during stage III (p_5) and relative growth rate at this date (p_4) significantly differed between altitudes. Fruits from low altitude during the 2002 and 2003 season had later p_5 and lower p_4 during stage III than those from high altitude during the 2002 and 2003 seasons. Fruits with higher relative growth rate (p_2) at high altitude in 2003 had lower cumulative growth (p_1) during the stage I than those from other altitudes or years. Lower p_1 affected cumulative growth (p_3) during stage III and resulted in smaller fruit at harvest. Fruits from both altitudes had similar size in 2002, while high altitude fruits were smaller than low altitude fruits in 2003 (Fig. 1A).

Modeled absolute growth rate is shown in Fig. 1B. In both altitudes and years, AGR exhibited an initial decline followed by a marked peak corresponding to the inflection point observed at about 157–158 or 132–140 days after full bloom at low and high altitude, respectively, during stage III (Table 2). Maximal AGR was lower in fruits from low altitude than those from high altitude in both years (Fig. 1B).

Second derivatives or absolute growth acceleration (AGA) was used to define growth stage II and, therefore, to determine the end of stage I and the beginning of stage III (Fig. 1C). Stage II was between 112 and 147 or 119 and 154 DAFB at low altitude, in 2002 and 2003, and between 105 and 126 or 112 and 133 at high altitude in 2002 and 2003, respectively. Stage II lasted longer at low altitude (35 days) than high altitude (21 days) for both years. Complete growth cessation occurred during the third week of October at 175

Table 2
Estimated fitting parameters and coefficients of determination (R^2) for cumulative fruit growth curves of diameters of pollination variant non-astringent 'Harbiye' persimmon fruits at low and high altitude in the East Mediterranean Region during 2002 and 2003.

Location	Year	p_0[a] estimate[b]	p_2 estimate	p_1 estimate	p_4 estimate	p_5 estimate	p_3 estimate	R^2
Low altitude	2002	3.39 ab	0.036 b	56.30 a	0.195 b	157.15 a	62.94 a	0.9984
Low altitude	2003	4.34 ab	0.038 b	57.44 a	0.218 b	158.07 a	63.14 a	0.9982
High altitude	2002	1.94 b	0.028 b	56.64 a	0.359 a	132.01 c	63.46 a	0.9999
High altitude	2003	10.69 a	0.053 a	47.54 b	0.337 a	140.63 b	54.81 b	0.9993

[a] p_0 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 the 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 during second period (stage III).
[b] NLMIXED procedure was performed to obtain the estimates of the parameters and statistical comparisons of parameters for each altitude and year by Wald's test. Means ($n = 5$) followed by same letter within a column are not significantly different at $P < 0.05$.

and 168 DAFB at low and high altitude, respectively. The duration of stages I, II and III was 105–119, 21–35 and 21–42 days, respectively, for 'Harbiye' persimmons grown at low and high altitude of the East Mediterranean region.

4.2. Total soluble solid and sugar content

TSS content increased during fruit growth (Fig. 2). During the 2002 season, TSS content was higher in fruits grown in low altitude

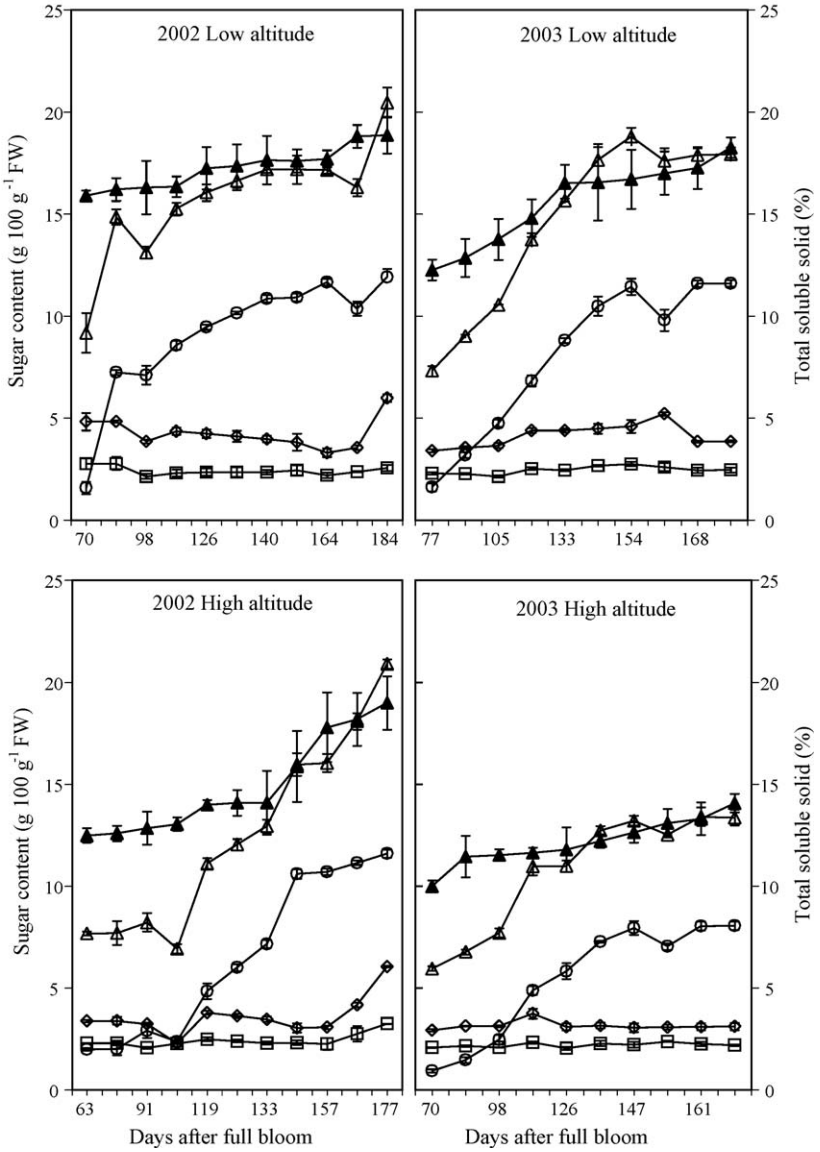


Fig. 2. Changes in fructose (□), glucose (◇), sucrose (○), total sugar (△) and total soluble solid (▲) content of pollination variant non-astringent 'Harbiye' persimmon fruits at low and high altitude in the East Mediterranean Region during 2002 and 2003. Each point represents the mean of five replicates (trees). Vertical bars denote standard error, and when absent fall within the area of the symbol.

than those grown in high altitude until growth stage III. Thereafter, fruits from both altitudes had similar TSS contents. During the 2003 season, low altitude fruits had a higher TSS content than those from a high altitude throughout the growth stages. Changes in individual sugars and total sugar content followed a similar trend to TSS content with regards to altitude and years (Fig. 2). Fructose and glucose content increased slightly during fruit growth. Sucrose content was lower than reducing sugars at the beginning of fruit growth, but it increased to higher levels than reducing sugars at the end of growth stage III. Total sugar content was consistent with TSS content.

4.3. Titratable acidity

TA decreased during fruit growth at both altitudes and years (Fig. 3A). Fruits had similar TA contents at both altitudes. There were significant differences in TA content between years. Fruits had lower TA content in 2003 than in 2002 at both altitudes.

4.4. Flesh firmness

Flesh firmness decreased during fruit growth and reached about 51–54 N during the third week of October at 175 DAFB at low altitude and 168 DAFB at high altitude in both years (Fig. 3B). Fruits had similar flesh firmness for both altitudes and years.

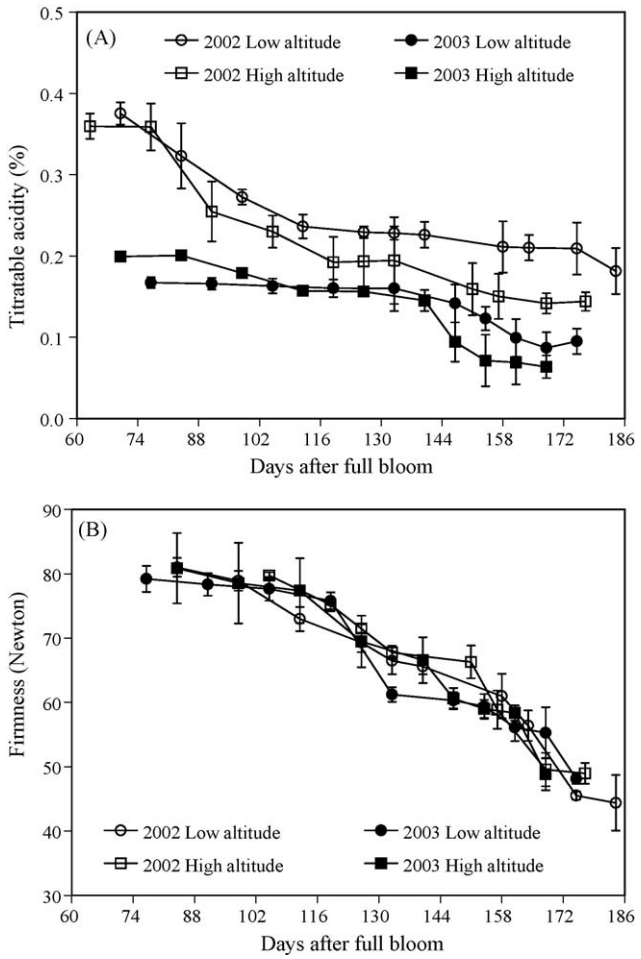


Fig. 3. Changes in titratable acidity (A) and flesh firmness (B) of pollination variant non-astringent persimmon 'Harbiye' fruits at low and high altitude in the East Mediterranean Region during 2002 and 2003. Each point represents the mean of five replicates (trees). Vertical bars denotes standard error, and when absent fall within the area of the symbol.

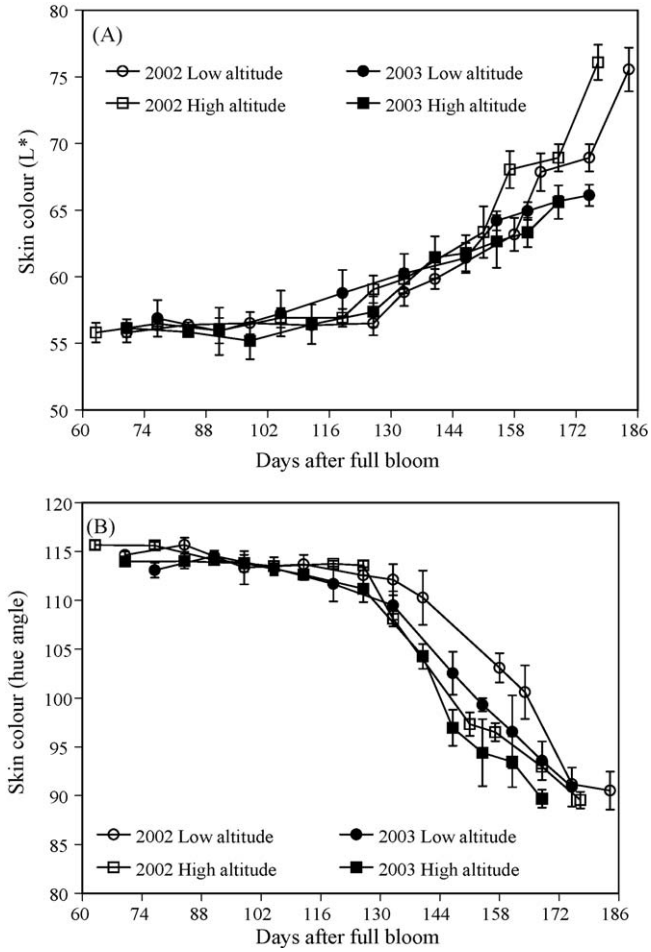


Fig. 4. Changes in skin colour L^* (A) and hue angle (B) value of pollination variant non-astringent persimmon 'Harbiye' fruits at low and high altitude in the East Mediterranean Region during 2002 and 2003. Each point represents the mean of five replicates (trees). Vertical bars denote standard error, and when absent fall within the area of the symbol.

4.5. Skin colour

Skin colour L^* (lightness) value increased (Fig. 4A), while hue angle (h°) value decreased (Fig. 4B) during fruit growth. Skin colour changes were more pronounced during stage III. There were no significant differences in L^* between altitudes and years.

No significant differences in h° value were observed between altitudes, but the significant decreases in h° value started earlier at high altitude than at low altitude.

4.6. Total carotenoid content

Total carotenoid content showed a decrease initially until 154 DAFB and 147 DAFB in low and high altitude, respectively (Fig. 5A), when stage II was completed. After reaching a minimum (colour break), there was a significant increase toward the end of the stage III. Total carotenoid content was higher in fruits from high altitude than those from low altitude during stage III.

4.7. Soluble tannin concentration

Soluble tannin concentration declined from the level of 0.10% to the level of 0.03% in the first week of August at 105 DAFB in low altitude and 98 DAFB in high altitude during stage I, and it remained at a similar level the rest of the growth period (Fig. 5B).

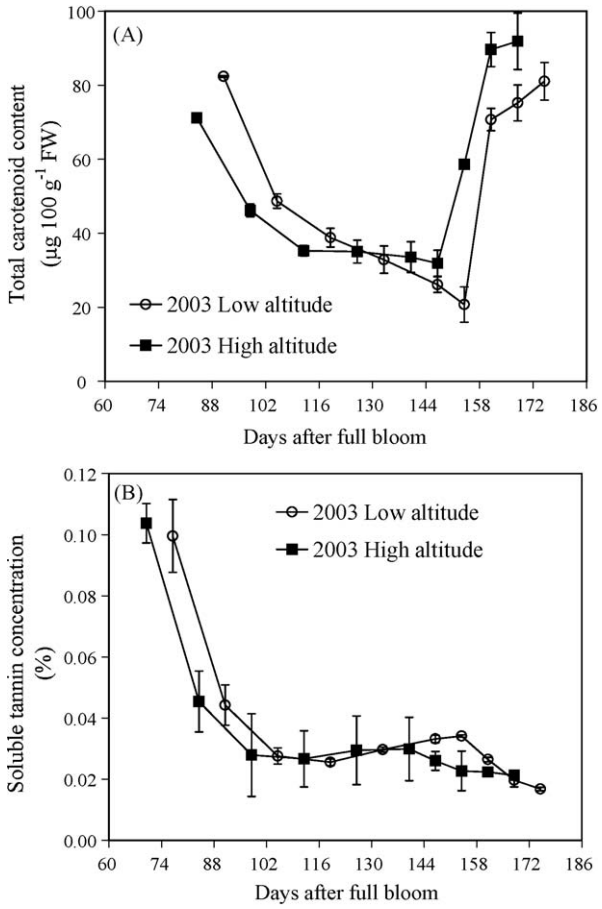


Fig. 5. Changes in total carotenoid content (A) and soluble tannin concentration (B) of pollination variant non-astringent persimmon 'Harbiye' fruits at low and high altitude in the East Mediterranean Region during 2002 and 2003. Each point represents the mean of five replicates (trees). Vertical bars denotes standard error, and when absent fall within the area of the symbol.

No significant differences in tannin concentration were observed between low and high altitude.

5. Discussion

Fruit diameter curves of 'Harbiye' persimmons followed a double sigmoid growth pattern, consisting of two rapid growth stages, stage I and stage III, separated by a period of slow growth (stage II), as reported previously by Zheng et al. (1990) and Sugiura et al. (1991) in other persimmon cultivars. The two-growth-curve model suggested by Genard and Bruchou (1993) in peaches could be used to analyze persimmon fruit growth since this model fits well the cumulative fruit growth at both altitudes and years (Fig. 1A). The parameters of this model provided useful information to identify the time of critical stages and to predict fruit size. Higher relative growth rate (p_2) resulted in lower cumulative growth (p_1) during stage I (Table 2). Similar phenomena were observed in peaches by Genard and Bruchou (1993). In contrast to Genard and Bruchou (1993) findings, lower p_1 affected cumulative growth (p_3) during stage III and resulted in lower fruit size at harvest. Stage I seemed to be critical for persimmon fruits. Similarly, Hirano et al. (1995) showed that artificial removal of calyx lobes at an early stage (such as stage I or II) markedly inhibited fruit growth and ripening of persimmon fruits. In this study, poor growth was probably due to high crop load that occurred in high altitude during 2003. This indicates that 'Harbiye' persimmons require early fruit thinning to increase fruit size when high crop load occurs.

Persimmon fruit growth ranges from 120 to 190 days, depending on cultivar and environment. The durations of Stages I, II and III are 60–100, 20–40 and 40–50 days, respectively (Mowat and George, 1996). In agreement with previous studies, the durations of stages I, II and III in our study were 105–119, 21–35 and 21–42 days, respectively, for 'Harbiye' persimmon grown in low and high altitude of the East Mediterranean region. There was a significant effect of altitude on the duration of the fruit growth stages. Stage II lasted longer in low altitude (35 days) than high altitude (21 days) in both years. As a result, the maximal absolute growth rate was lower and occurred later in fruits from low altitude than high altitude during stage III. In persimmon fruits, the retarded or slow fruit growth in stage II was attributed to very high day and night summer temperatures (Sugiura et al., 1991). Stage II coincided with the last week of August to the third week of September when higher day and night temperatures occurred in low altitudes than high altitude, as seen in Table 1. This means that higher temperatures retard growth and/or ripening of persimmon fruit, while cooler temperatures accelerate it. This theory was previously supported by artificial temperature regimes applied to persimmon fruit trees (Sugiura et al., 1991). Sugiura (2005) suggested that the delayed the onset of stage III or longer stage II by high temperatures was as a result of the effects of the temperature on the endogenous gibberellic acid (GA) and absisic acid (ABA) activity. Higher temperature seemed to delay the reduction of endogenous GA activity, while lower temperatures to increase ABA content in the fruit. Another study by Nakano et al. (1997) showed that GA treatment during growth stage II retarded final swell and respiration rise at growth stage III. Contrarily, ABA treatment before entering growth stage III slightly increased fruit growth and respiration rate. Authors suggested that the respiration rise with the onset of growth stage III may be a key factor for inducing phase change from growth stage II to growth stage III. The effects of altitude and/or air temperature on the respiration rate and endogenous GA and ABA content of 'Harbiye' persimmon fruits needs further investigation.

There was no significant effect of altitude on the chemical changes of 'Harbiye' persimmons except for colour changes. Colour break occurred earlier in high altitude than low altitude. This is evident from the significant decreases in h° value (Fig. 4B) and increases in total carotenoid content after reaching minimum (Fig. 5A). At harvest, fruits from both altitudes had similar sugar content (Fig. 2) and soluble tannin concentration (Fig. 5B). However, TSS and sugar content was lower in fruits from high altitude during the 2003 season. This was probably caused by poor growth. Similar results were reported by Zheng et al. (1990), who compared the phenology of persimmon in two locations with distinctly different temperature conditions. The authors observed that the yellowing of astringent and non-astringent persimmon fruits started earlier at the lower temperature site, but the final colour intensity was more advanced at the higher temperature site. Total sugar and soluble tannin contents in the flesh at maturity were quite similar for the two sites.

Changes in the skin colour were closely related to an increase in sugar and a decrease in firmness. The greatest increase in TSS content occurred in the final month before harvest during stage III (Fig. 2), when pronounced changes in skin colour (Fig. 4) and softening of fruits (Fig. 3B) were observed. Total soluble solid and skin colour were reported as important maturity indices for persimmon fruits (Testoni, 2002; Crisosto et al., 2006). TSS of 18–20% and yellow or yellowish-green skin colour are recommended for optimum quality in Fuyu and similar non-astringent cultivars (Crisosto et al., 2006). Our data indicated that 'Harbiye' persimmons met the optimum TSS content (Fig. 2) and minimum colour requirements (Fig. 4B) during the third week of October at 175 DAFB in low altitude and 168 DAFB in high altitude, except for fruits from high altitude during the 2003 season. The TSS content of these

fruits did not exceeded 14%, which still met export requirements (George et al., 1994). The optimum harvest time could also be identified at the end of stage III, when fruit growth concluded (Testoni, 2002). Complete diameter growth cessation occurred during the third week of October at 175 and 168 DAFB at low and high altitudes, respectively (Fig. 1A). Therefore, the 175 and 168 DAFB were concluded to be the optimum harvest time for persimmon 'Harbiye' at low and high altitudes of the East Mediterranean region, respectively. Flesh firmness at harvest is also an important criterion to maintain quality during the postharvest period. Non-astringent persimmon fruits are considered to have attained a firm ripe stage when flesh firmness reaches about 51–54 N (Harker and Forbes, 1997). In 'Harbiye' persimmons, this stage was reached during the third week of October at 175 DAFB in low altitude and 168 DAFB in high altitude in both years (Fig. 3B).

Glucose and fructose are generally considered the main sugars, while sucrose is present as a minor component in mature persimmon fruits (Glew et al., 2005). In contrast, sucrose was the predominant free sugar identified followed by glucose and fructose in 'Harbiye' persimmons (Fig. 2). In agreement with our results, Senter et al. (1991) found that level of sucrose exceeded quantities of glucose and fructose at all maturity stages in some non-astringent persimmon cultivars. Zheng and Sugiura (1990) suggested a classification as sucrose and reducing sugar accumulating persimmon cultivars depending on free invertase activity during growth and maturation. Sucrose content of 'Harbiye' persimmons comprised 60–70% of the total sugars, which indicated that 'Harbiye' is a sucrose-accumulating cultivar.

Total carotenoid content of 'Harbiye' persimmons showed a decrease initially until the slow fruit growth of stage II ended, and it then exhibited a significant increased toward harvest maturity. Similar changes in carotenoid content have been reported with Triumph persimmon (Ebert and Gross, 1985). According to the authors, the changes in the total carotenoid content during ripening showed a minimum when the fruit began to turn yellow-orange (colour break) and then increased drastically at the last ripening stages due to massive synthesis of carotenoids as chlorophyll disappeared.

'Harbiye' showed changes in soluble tannin concentration typical of pollination variant non-astringent type persimmons (Sugiura and Tomana, 1983). Soluble tannin concentration decreased to the level of 0.03%, at which time fruits became non-astringent based on the scale suggested by Orihuel-Iranzo et al. (2003). Natural loss of astringency occurred in the first week of August at 105 DAFB in low altitude and 98 DAFB in high altitude (Fig. 5B), which was the end of stage I.

6. Conclusion

This study demonstrated that a two-growth-curve model fitted well the persimmon fruit growth which follows a double sigmoid growth pattern. The time from full bloom to maturity in 'Harbiye' persimmons was longer in low altitude than high altitude due to longer stage II. 'Harbiye' persimmons reached optimum quality at 175 DAFB and 168 DAFB (late October) at low and high altitudes of the East Mediterranean region, respectively.

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