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Research Article

Quality of Different Papaya Cultivars Grown in the Greenhouse throughout the Year in Subtropical Regions

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Abstract: Harvest time is one of the factors affecting postharvest fruit quality. Under the subtropical condition, greenhouse cultivation allows a year-round harvest. However, the crop should meet the quality and the marketing criteria for overall customer satisfaction. This study aims to determine the impact of the harvest season on the quality characteristics of papaya fruit. For this purpose, two different cultivars (*Sel-42* and *Tainung*) were grown in the greenhouse and harvested in the winter, the summer, the spring, and the autumn of two years. Sampling was carried out at the same visual maturity stage at each season. The two cultivars had soft fruit flesh almost throughout the year, although the fruit harvested in the winter had a better visual appeal in terms of color. Both fruit cultivars harvested in the autumn had higher soluble solids and lower acidity. The highest concentrations of total phenolic content and L-ascorbic acid were observed in the spring and summer season harvested fruits although there was no significant difference between those ($P > 0.05$). It was concluded that the growth in the greenhouse minimizes the harvest season effects on papaya fruit quality. Thus, greenhouse cultivation is recommended for a higher quality product, especially in a subtropical climate.

***Keywords*:** papaya fruit, seasonal changes, greenhouse crop, harvest season, *Sel-42*, *Tainung*, phytochemistry

Abbreviations

AA: L-ascorbic acid
SS: Soluble Solids
TA: Titratable Acidity
TPC: Total Phenolic Content

1. Introduction

Cultivars, harvest season, soil composition, and agrotechnical procedures are among the factors affecting the physicochemical properties and fruit's quality [1-4]. It is essential to control the crop cultivation conditions in order to

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provide customers with year-round production of high-quality fruit. In the case of papaya, greenhouse cultivation seems to be effective in achieving this goal [5]. Cultivation in a controlled environment provides adequate temperatures needed also to prevent the incidence of Papaya Ringspot Virus (PRSV) [6].

Various parts of papaya are very rich in nutritional compounds [7]. The fruit contains many nutrients such as phenols, alkaloids, flavonoids, tannins, Vitamin A, Vitamin C, niacin, folic acid, thiamine, riboflavin, and also rich in β-carotene [8, 9]. The chemical composition of the fruit changes during the stages of fruit development. While moisture content is not changed significantly, dry matter, crude fiber, ash, protein, fat, and carbohydrate contents of the fruit decreases during ripening [10, 11]. Papaya fruit is very susceptible to postharvest losses due to its climacteric nature [12]. Thus, the ripening conditions affect the quality and the nutritional composition of the fruit. Previous studies were carried out to identify the interaction between ripening conditions and fruit quality examining various cultivars and various ripening stages [11, 13-17]. However, to the best of our knowledge, there has been no study investigating the effect of the harvest seasons on the physicochemical properties of the papaya fruit at harvest maturity in greenhouse.

Greenhouse cultivation is important to allow the production of fruit and vegetables throughout the year by protecting plants against environmental changes. Therefore, the aim of this study was to investigate the physicochemical properties of papaya cultivars at the same harvest maturity grown in a greenhouse at different harvest seasons. Two papaya cultivars (*Sel-42* and *Tainung*) were harvested at the same visual maturity stage at all four seasons. The traits: fruit color, flesh firmness, soluble solids/titratable acidity ratio, total phenolic content, and L-ascorbic acid were analyzed.

2. Materials and methods

2.1 *Materials*

F1 hybrid papaya cultivars of *Sel-42* and *Tainung* were used in the experiments. All analytical chemicals were obtained from Sigma-Aldrich (St Louis, MO, USA). For chromatographic analysis, deionized water of 18.2 MOhm resistivities, purified with a Milli-Q system (Millipore, Bedford, USA) was used.

2.2 *Growth conditions and harvest time*

This research was conducted between 2009 and 2011 in a 1000 m^2 plastic greenhouse (Latitude: N 36 ° 54 028 ', Longitude: E 30 ° 38-810 ', Altitude 38 m) belonging to Seed Research and Development Center of Akdeniz University. The papaya plants were transplanted on the 28^{th} of March 2009 at 2.5 m intervals between the plants on a line (1.8 m intervals between the lines inside of the greenhouse). A drip irrigation system and a fertilization program were applied. The moisture content, electrical conductivity, and pH values of the soil were measured with a tensiometer on the next day of drip irrigation in the greenhouse. Irrigation and fertilization were done by considering these measurements and climatic values. The fertilization program was based on soil analysis. The fertilization was applied in 5-6-day periods according to the water requirement of the soil. After drip irrigation, approximately 350 g N, 225 g P_2O_5, 550 g K_2O, 25 g MgO and 5 g CaO were applied during the vegetation period. Fertilization was based on the ratio of 1:3:1 (Nitrogen-Phosphorus-Potassium) in the first three applications after planting, followed by the ratio of 2:1:3 until fruit development and finally based on the ratio of 3:1:6 during fruit development. During the cultivation, a mini meteorology station (HOBO, Tartes Agri. Ind. Comm. Ltd., Turkey) was placed in the greenhouse to record the temperature and Relative Humidity (RH) from April 2009 to October 2011. The measurements were taken hourly.

The papaya fruits were harvested in the months of January, April, July, and October representing the seasons of winter, spring, summer, and autumn during 2010 and 2011. Harvesting the fruit at the full ripeness stage leads to short shelf life. Therefore, commercial harvest is generally carried out when the peel (exocarp) color turns yellow (from dark or light green), approaching one-quarter to one-half depending on the distance to the market [18]. In the study, the fruits were harvested at the same ripening stage (one-third yellow on fruit peel; Ripening Stage-3 [RST3]) [19].

2.3 *Methods*

2.3.1 *Peel color*

A colorimeter with light source D65 and 10 ° observer (Minolta Chroma Meter, CR300, Minolta, Osaka, Japan) were used to assess the peel color of harvested papaya fruit [20]. The triplicate measurements of L^*, a^*, and b^* values were taken around the fruit equator. The a^* and b^* values were used to calculate hue angle [$h°$ = arctan (b^*/a^*)] and chroma values ($C = (a^{*2} + b^{*2})^{0.5}$) [21]. L is defined as lightness (luminosity) within the range of 0-100 (0: black, 100: white) [22]; $h°$ *(Hue angle)* is defined as what the color is (red at 0 °, yellow at 90 °, green at 180 °, blue at 270 °); C^* (Chroma) is defined as the intensity or depth of color [23]. The higher the C^* values, the higher the color density of the samples perceived [24].

2.3.2 *Flesh firmness*

The firmness of the papaya fruit flesh was measured by Effegi penetrometer (Model FT 327, EFFEGI, Milan, Italy) fitted with a 7.9 mm Effegi probe. The fruit was peeled then measurements were taken from three different surface points of each fruit. The average values of the measurements were expressed as a Pa unit.

2.3.3 *Calculation of ripening index (SS/TA)*

Ripening Index (SS/TA) was calculated by dividing Soluble Solids (SS) to Titratable Acidity (TA). The juice of the papaya fruit was extracted with a juicer and subjected to SS analysis using a hand refractometer (ATC HT113, China) and TA analysis was performed using a pH meter (Thermo Scientific™ Orion™ 3-Star, USA) and 0.1 N NaOH solution). Soluble solids and TA values were expressed as a percent and citric acid equivalent (g citric acid 100 g^{-1}), respectively [25].

2.3.4 *Determination of Total Phenolic Content (TPC)*

Total Phenolic Content (TPC) was determined with Folin-Ciocalteu's phenol reagent with reference to the method of Slinkard and Singleton [26]. Accordingly, all fruit samples and gallic acid standards were dissolved in 50% methanol using the equation obtained from the standard. Then 0.5 ml of sample, 2.5 mL of Folic-Ciocalteu's phenol reagent, and 7.5 ml of Na_2CO_3 solution (20%, w/v) were put in a tube and mixed using a vortex. All samples were kept in the dark for 2 hours. Then the absorbance values of the samples were measured at 750 nm using a UV-VIS spectrophotometer (Thermo Scientific Evolution 201 UV-VIS Spectrophotometer, USA). All results were expressed as Gallic Acid Equivalent (GAE) per 100 g sample by using a calibration curve prepared with a series of gallic acid standards (0-200 mg L^{-1}).

2.3.5 *Determination of L-ascorbic acid*

The concentration of L-ascorbic acid was determined according to Karhan, Aksu [27]. Sixty g of the edible fruit was transferred to 250 mL of the volumetric flask containing 10^{-6} M ethylenediaminetetraacetic acid (EDTA), 10^{-7} M diethyldithiocarbamic acid, and 6% HPO3. The mixture was homogenized at 24,000 rpm with an Ultra-Turrax homogenizer (IKA T8, Germany), then centrifuged at 3,000 rpm for 20 minutes. The supernatant was first filtered through Whatman No: 42 filter paper then through a 0.45 µm membrane filter. Quantification was calculated by an external standard method using the L-ascorbic acid standard.

The HPLC system consisted of Shimadzu LC-20 AD Solvent Delivery System (Japan) equipped with the column of Nucleosil 5 C18 (250 × 4.6 mm I.D.). The separation was carried out by isocratic elution (1.5% of $NH_4H_2PO_4$) with a flow rate of 0.9 ml min^{-1}. The column temperature was ambient. The eluate was detected using a Shimadzu DAD-M20 A photodiode array detector set at 264 nm. The injection volume was 20 µL.

2.3.6 *Statistical analysis*

Per each harvest period representing the different seasons, 5 fruits were harvested from every plant with three replications (N = 15 per each season). Statistical analysis was examined by the One-Way Analysis of Variance (One-Way ANOVA) method followed by Tukey's multiple range test. Statistical significance was tested at $P \leq 0.05$. All analyses were carried out with OriginPro 2019b statistical package (OriginLab Corporation, 9.6.5.169).

3. Results

During the cultivation of the papaya plants in the greenhouse, the lowest and highest temperature and RH values as the average of measured years (2009-2011) were 13.3 °C ± 1.16 °C and 30.30 °C ± 0.45 °C with 57.79% ± 9.52% and 80.68% ± 4.75%, respectively (Figure 1).

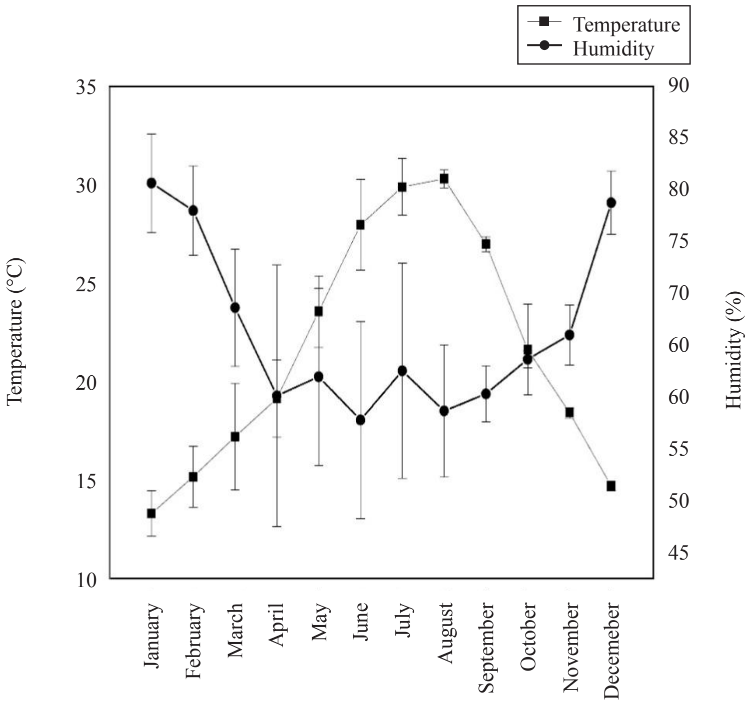

Figure 1. Climatic data of papaya cultivated in greenhouse [Values are the average of years (from April 2009- to October 2011) of measurement]

These climatic data were used to interpret the changes in chemical and organoleptic properties of the fruits in the study. Because it is stated that especially the cultivation in subtropical climate conditions, where the daily temperature decreases below 11 °C, harms the fruit development [28].

3.1 *Peel color*

There was no difference in the peel color of the harvested fruit. However, in general, the fruit harvested in the colder seasons (autumn and winter and even the spring) had a more yellow color. On the other hand, although C^* values indicating the purity, or the density of the yellow color was not significantly different between the various harvest seasons ($P > 0.05$), the samples harvested in the summer and autumn seasons had higher values ($P < 0.05$; Figure 2).

No significant difference between the two cultivars in terms of hue angle, chroma, and lightness were found ($P < 0.05$). While the highest $h°$ value (79.71 °, higher yellow) was observed in *Sel-42* fruit cultivar harvested in the winter season, the lowest $h°$ values (56.92 ° for *Sel-42*; 58.54 ° for *Tainung*) were observed for both fruit varieties in the summer season (Figure 2). In terms of lightness, the *Sel-42* harvested in autumn (L: 65.68) had the highest value among all. The fruit of both cultivars harvested in the summer had lower L values.

3.2 *Flesh firmness*

The flesh firmness of *Sel-42* significantly decreased during the seasonal transition from winter to summer then increased in autumn. On the other hand, the flesh firmness of *Tainung* decreased steadily from the winter to autumn period (Figure 3).

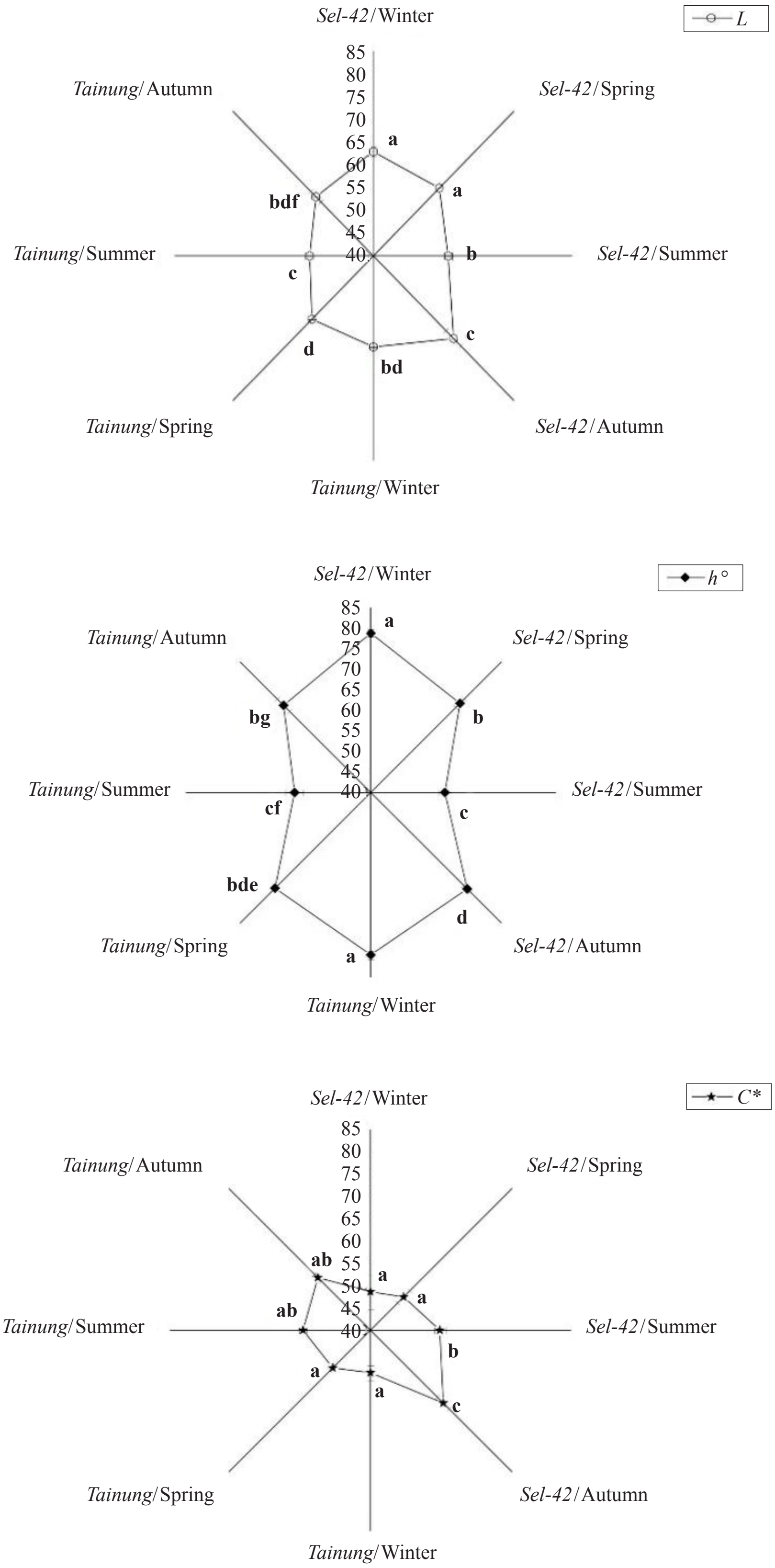

Figure 2. Color (*L*, *C*, *h*°) values of *Sel-42* and *Tainung* papayas (Different letters represent significant differences at P < 0.05)

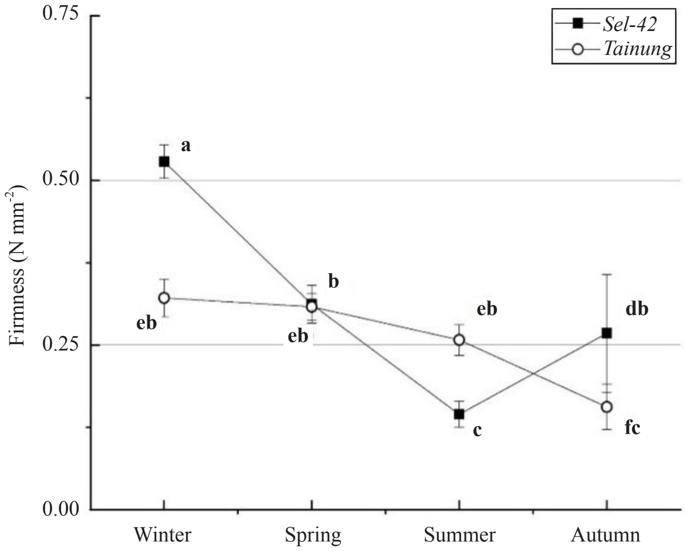

Figure 3. Flesh firmness of *Sel-42* and *Tainung* papayas (Different letters represent significant differences at $P < 0.05$)

Comparison of both cultivars showed that the *Sel-42* was generally softer, while *Tainung* cultivated in autumn and *Sel-42* cultivated in the summer have the same firmness ($P > 0.05$). The highest firmness value (0.53 $N.mm^{-2}$) was observed in *Sel-42* papaya fruit harvested in the winter season among all. The fruit for this cultivar harvested in summer had the softest flesh compared to the other seasons (Figure 3).

3.3 Chemical ripening index (SS/TA)

Soluble Solids (SS) and Total Acidity (TA) values of all samples were between 8.48% ± 0.48-11.71% ± 0.23 and 0.094 ± 0.006-0.12 ± 0.002 g citric acid 100 g^{-1} (Table 1).

Table 1. Soluble Solids (SS) and Titratable Acidity (TA) values of *Sel-42* and *Tainung* papaya fruits

Papaya cultivar	Season	SS (%)*	TA (g citric acid 100 g^{-1})*
Sel-42	Winter	$9.40^{a} \pm 0.83$	$0.11^{a} \pm 0.01$
	Spring	$8.90^{a} \pm 0.83$	$0.13^{b} \pm 0.00$
	Summer	$10.68^{b} \pm 0.25$	$0.10^{a} \pm 0.00$
	Autumn	$11.71^{c} \pm 0.24$	$0.10^{a} \pm 0.01$
Tainung	Winter	$8.48^{a} \pm 0.48$	$0.10^{a} \pm 0.01$
	Spring	$8.70^{a} \pm 0.23$	$0.12^{a} \pm 0.00$
	Summer	$8.81^{a} \pm 0.44$	$0.11^{a} \pm 0.01$
	Autumn	$9.87^{b} \pm 0.35$	$0.09^{a} \pm 0.01$

*: Different letters within the same column represents significant differences at $P < 0.05$

Statistical analysis showed no significant difference between *Sel-42* harvested in the summer and autumn seasons and *Tainung* harvested in the autumn season ($P \leq 0.05$). This could be due to the high ratio of sugar to acidity, making the fruit more palatable. Among all samples harvested at different seasons; both papaya cultivars harvested in autumn had the highest SS values (11.71% for *Sel-42* and 9.87% for *Tainung*, Figure 4).

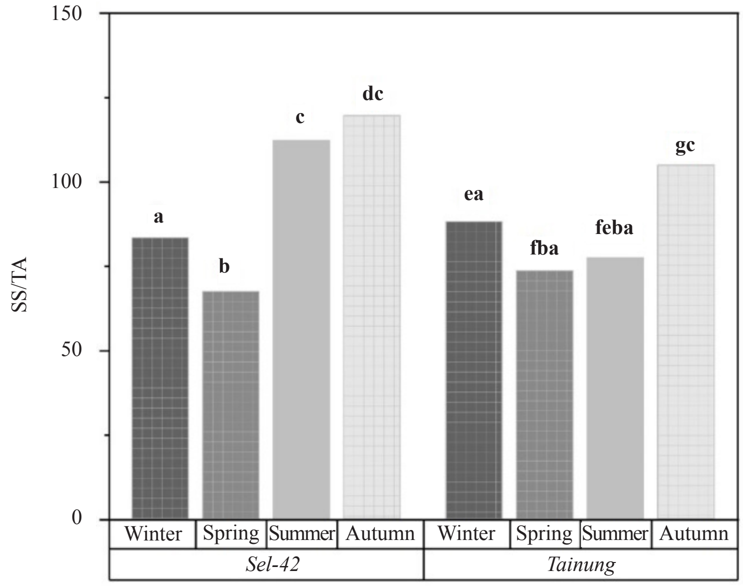

Figure 4. Ripening index of *Sel-42* and *Tainung* papayas (Different letters represent significant differences at $P < 0.05$)

3.4 *Total Phenolic Content (TPC)*

Total phenolic contents of *Sel-42* and *Tainung* did not significantly change except the highest TPC values observed in *Sel-42* papayas harvested in spring (137.73 mg GAE 100 g^{-1}) and summer (144.43 mg GAE 100 g^{-1}) seasons (Table 2, $P > 0.05$). *Tainung* papayas had relatively lower TPC values (93.33-97.27 mg GAE 100 g^{-1}) than *Sel-42* papayas (102.25-144.43 mg GAE 100 g^{-1}).

Table 2. Total Phenolic Content (TPC) and L-ascorbic acid (AA) values of *Sel-42* and *Tainung* papaya fruits*

Papaya cultivar	Season	AA (mg AA 100 g^{-1})	TPC (mg GAE 100 g^{-1})
Sel-42	Winter	$61.86^{a} \pm 5.15$	$102.25^{a} \pm 9.66$
	Spring	$86.77^{b} \pm 19.08$	$137.73^{b} \pm 24.88$
	Summer	$85.13^{b} \pm 17.67$	$144.43^{bc} \pm 22.99$
	Autumn	$76.32^{a} \pm 12.56$	$114.88^{a} \pm 11.93$
Tainung	Winter	$63.88^{a} \pm 1.09$	$93.33^{a} \pm 3.37$
	Spring	$68.08^{ab} \pm 2.71$	$92.95^{a} \pm 7.10$
	Summer	$67.81^{ab} \pm 2.62$	$93.75^{a} \pm 2.39$
	Autumn	$64.86^{a} \pm 2.67$	$97.27^{a} \pm 11.58$

*: Different letters within the same column represents significant differences at $P < 0.05$

3.5 *L-ascorbic acid*

L-ascorbic acid (AA) content followed the same trend as TPC value for the cultivars *Sel-42* and *Tainung* depending on the seasons (Table 2). Accordingly, the highest AA values were obtained in *Sel-42* harvested in spring (86.77 mg AA 100 g^{-1}) and summer (85.13 mg AA 100 g^{-1}), although there was no statistically significant difference between the two seasons ($P > 0.05$). On the other hand, seasonal changes did not affect the AA content of *Tainung* grown in the greenhouse ($P > 0.05$). In the winter and autumn seasons, *Sel-42* papaya had similar AA contents as *Tainung* harvested throughout the year ($P > 0.05$). While there was no significant seasonal difference in terms of ascorbic acid in tainung papaya harvested in different seasons, the highest concentrations were reached in the samples harvested in spring and summer in *Sel-42* variety (Table 2). Change in AA concentration may be due to the exact ripening stage at which the harvest takes place or due to different cultivars [29].

4. Discussion

4.1 *Physical characteristics of papaya fruit*

Skin color is one of the important attributes to define fruit ripening. The parameters indicating the color change through this period. For example, the lightness (L) of the skin part of papaya decreases as the fruit ripens [30]. Schweiggert, Steingass [31] also reported L, C, $h°$ color values indicating bright yellow color formation during papaya ripening on tree as 61.2, 61.2 and 77.2 °, respectively. The L and $h°$ values of the harvested fruits were similar to the values reported by Schweiggert, Steingass [31], but the authors recorded higher C values than the results of this study. This difference might be due to the Costa Rican hybrid “Pococi” they used and their experiment condition of an open field. Results of this study indicate that especially in colder climates, the yellowness of the fruit increases.

Flesh firmness is an important indicator for fruit quality and should be maintained during postharvest storage and shelf-life period [32]. Very low firmness values (as the lowest 0.14 ± 0.019 $N.mm^{-2}$ and the highest 0.53 ± 0.025 $N.mm^{-2}$) were observed for *Sel-42* and *Tainung* compared to those obtained by Bron and Jacomino [14]; Pinillos, López [33] that reported higher firmness values than this study for papaya fruit in greenhouse cultivation at various harvesting periods. This difference may be due to the different papaya cultivars (*Golden* and *BH-65* papayas) that were chosen for their experiments. In comparing the firmness of papaya in subtropical climate and greenhouse cultivation conditions, although the sample papaya species reached the softest level in different seasons (*Tainung*: Autumn, *Sel-42*: Summer; $P < 0.05$), the hardness of the samples harvested at the same maturity level remained almost the same throughout the year ($P > 0.05$).

4.2 *Chemical characteristics of papaya fruit*

Sugars and organic acids can be affected by seasonal dynamics [34]. They are important components responsible for the flavor of papaya thus affecting the sensory attributes of the product [35]. Ripening index (Sugar/Acid ratio) is considered as the best objective measurement reflecting consumers’ perception thus it is highly important to be assessed [36]. Although Kader [37] indicated that the suggested minimum for SS level in papayas being 11.5% for the total SS level, Nakasone and Paull [18] are a little bit more precise indicating as acceptable an average of 11.5% for any lot of papayas, provided that no more than 5% by count of the fruit in the lot have SS less than 10.5%. Thus, it is thought that *Sel-42* harvested in the autumn season in this study (SS value of 11.71%) may be preferred by the consumers (see Table 1). However, it may be also possible that the *Tainung* harvested in the autumn can also be sensorially accepted in terms of ripening index due to its relatively low acidity (0.094 ± 0.006) and soluble solids close to the minimum acceptable level (9.87 ± 0.35), values similar to literature findings [38] for fully ripe *Tainung* (10.70% for SS, 0.085 g ml^{-1} for TA, SS/TA: 141.27). Generally, there is a negative correlation between sugar content and fruit firmness during the ripening period [39]. This is due to the accumulation of sugars in fruit tissues. Thus, softening occurs with an increasing concentration of sugars [40]. This agrees with the obtained results in the current study. In fact, there was a moderately negative correlation ($r = -0.30$) between sugar and firmness values means that the papaya fruits with high sugar content had lower firmness (Figure 3 and 4).

The value of TPC (92.95 mg GAE 100 g^{-1}) of *Tainung* harvested in the spring (April) was higher than reported by Özkan, Gübbük [41]. These authors also analyzed the TPC content of *Tainung* harvested in May at a commercially ripe stage of one-fourth yellow color in the peel. They reported a TPC value of 42 mg GAE 100 g^{-1}. This difference might be due to the different ripening stages for harvesting (in this study, one-third yellow color was the time of harvest). In addition, the climate and the cultivation conditions may have affected the chemical composition of the fruit. Several studies have tested the effect of the ripening stage on the physicochemical properties and especially TPC [17, 42]. However, since in this study, the physicochemical properties of the fruit harvested at various seasons at approximately the same harvest maturity level were examined, it was not possible to precisely compare our results with the aforementioned studies, especially those in which, the harvest season of the fruit was not clearly stated.

Kelebek, Selli [43] compared the chemical compositions of *Sel-42* and *Tainung* that were harvested in May at the commercially ripe stage (one-fourth yellow color in fruit peel) and reported that *Sel-42* had a higher AA concentration (71.70 mg AA 100 g^{-1}) than *Tainung* (67.30 mg AA 100 g^{-1}). This result agreed with the findings of this study.

5. Conclusion

This study shows that under the condition of this experiment the papaya fruit harvested in colder seasons (approximate measured climatic values were 13-22 °C, 64-81% RH, Figure 1) had better physical properties (bright, yellow color, soft tissue texture) for the consumers than those harvested in warmer weather in the same location. Papaya cultivars especially harvested in autumn had higher sugar content (soluble solids) and relatively lower acidity. The sugar/Acid ratio is an important parameter of fruit sensory attraction. Accumulation of total phenolic content and L-ascorbic acid in the fruit tissues was not affected by the seasonal harvest.

Considering the results obtained from this study, it can be concluded that there is the possibility to produce papaya fruit in the subtropical areas of Turkey. However, further studies should be implemented for the evaluation of fruit yield/quality characteristics and consumer acceptance by growing different cultivars of this fruit so that a crop with high economic return for the farmers would be suggested.

Acknowledgements

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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