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Effect of Different Harvest Dates on the Quality of Beauty and Japanese Plum Fruits after Ripening

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Abstract : Plum fruits considered as a good source of natural antioxidant substances. Consumer acceptance and market life of plum fruit (*Prunus salicina* L.) were extremely dependent on harvest date. Two plum cultivars, 'Beauty' and 'Japanese' were harvested at different commercial maturity stage and then ripened at 20^{O}C for 7 days during two successive seasons 2013 and 2014. Plum fruit quality attributes were studied for carbon dioxide production, oxygen uptake, skin and flesh color, fruit firmness (N), soluble solids content (SSC), total acidity, SSC/acid ratio, ascorbic acid (vitamin C), and total anthocyanin content. Fruit quality parameters appeared significant differences throughout different dates of harvesting and after ripening. In both cultivars, CO_2 production showed fewer increase than O_2 uptake as a result of harvest dates. Meanwhile, the opposite trend were noticed after ripening. Plum color parameters as L*, Hue angle and Chroma were significantly varied in both cultivars, either in skin or flesh fruit. A significant increase in SSC, SSC: acidity ratio and ascorbic acid were observed while flesh firmness and total acidity were decreased at the same date. The highest content of anthocyanin of fruit skin was noticed at the late harvest date. Therefore, plum fruit with more mature was better than less mature one, which had lesser quality when ripened. Less maturity harvest grade was accompanying with inability of plum fruit to ripen for its remaining firmer after harvest.
Key words: Plums, Fruit quality, Harvesting dates, Skin color, Ascorbic acid, Anthocyanin and Ripening index.

Introduction

Since ancient times, fruits have been found to have both a protective and a healing role. Among these fruits, plums are especially rich in vitamins, fibers, phenolic and antioxidants[1]. Plum have a climacteric ripening manner and show a degree of variability in its characteristics depending on the time of harvest. Plums can endure cold storage better if they are harvested at earlier maturity. At harvesting time, the maturity stage of plum is an essential aspect in affecting the quality of the fruits, for its damaging properties of picking at either more early or late maturity[2,3]. Meanwhile, plum fruit with less mature has worse quality than both harvested at progressive maturity stage. Also, when plums might be harvested more mature, it's quality characteristics will be progressed[4]. So, reduction of fast softening should be avoided during postharvest handling to protect fruit quality and increase shelf life of delayed harvested fruit. Plum consumer acceptance and market life are highly dependent on harvest date, and plums should be marketed and consumed within their potential market life[5,4]. As fruit mature, the sugars become the main component of the soluble solids[6]. Sugar accumulation is considered an early event during fruit growth in most of fruits[7]. Sensory evaluation of 'Green Gage' plums showed that the most valuable fruit were those with high levels of sugars, the accumulation is mainly due to translocation of assimilates from photosynthetic leaves. Low levels of acidity and intermediate firmness[8]. As with other climacteric types, the softening in fruit flesh and the increase in TSSC (total soluble solids content) are the basic parameters indicating the start of maturation[9,10].

Plum fruit color during fruit maturation and ripening changes from green to red, yellow, or purple depending on the cultivar. The anthocyanins are the main phenolic compounds in the skin of plum fruit, especially red and purple cultivars[11,12]. Therefore, it is important for the grower to be able to determine the precise stage of crop development in order to allow harvestat a time that is optimal for the storage process[13]. Generally, a compromise between an earlier and a late harvest has to be reached to achieve the premium quality for consumer and in the same time extend postharvest life for marketing.

The main objective of this study was to evaluate the effect of different harvest dates at maturity stage on the postharvest behavior and fruit quality of plum Beauty and Japanese cultivars during ripening.

Materials

Fruit:

Plum fruits (*Prunus salicina* L.) cvs. Japanese and Beauty grafted on Mariana rootstock were harvested in 2013 and 2014 seasons from a private orchard located in Zayed district, Minufiya governorate, Egypt. Fruits were handpicked from twenty years old trees grown in clay soil that were similar in growth and received common horticultural practices. Undamaged fruits, free from visual blemishes, uniform in shape, weight, color and firmness were harvested, graded, packed and transported on the day of harvest to the postharvest laboratory of Agricultural Development System (ADS) project in Cairo University.

Treatment:

Fruits were harvested on June 1, June 7, June 15 and June 21. On each harvest date, fruits were washed, air-dried and held in a controlled temperature chamber at 20ºC and 80-85% RH for seven days for ripening. Fruits were analyzed for physico-chemical characteristics at every harvest date and after ripening at 20^0C. Three replicates for each harvest date and ripening period were used and each replicate consists of ten fruits.

Methods

Fruit quality assessment:

At each harvest time and following ripening at intervals of 7 days, the plum fruit were assessed for Firmness (N), CO_2 Production, O_2 uptake, skin and flesh color, Soluble solid content, Total acidity, TSS/Acid ratio (%), Ascorbic acid content, Total anthocyanins content for skin fruits.

CO_2 production and O_2 uptake: Fruits of each harvest date and after ripe at 20ºC were weighed and placed in 1-liter jars at room temperature or 20ºC. The jars were sealed for 24 hr. with a cap and a rubber septum. O_2 and CO_2 samples of the headspace were removed from a septum with a syringe and injected into Servomex Inst. (Model 1450C, Food Pack Gas Analyzer) to measure oxygen and carbon dioxide production[14,15].

Fruit firmness (Newton): firmness was determined using Ametek pressure tester and fitted with a 7.9 mm hemispherical probe (probe penetration 2 mm). Measurements were taken at two equatorial positions on each fruit replicate. The results were expressed in Newtons[16].

Color measurements: Color was measured with a Minolta colorimeter (Minolta Co. Ltd., Osaka, Japan) on the basis of the CIELAB color system (L*, a*, b*, C*, and h◦). In this system, L*, a* and b* describe a three dimensional color space, where L* (Lightness) is the vertical axis and its value varies from 100, for perfect white to zero, for black. Values of a* and b* specify the green-red and blue-yellow axis, respectively. Chroma (C*) describes the length of the color vector, while Hue (h◦) determines the position of such vector. C*and h◦ values are calculated based on a* and b* values according to the following equations: C* = [(a*) 2 + (b*) 2] 0.5 and h◦ = $\tan^{-1}$ (b*/a*). Five fruits were measured objectively by averaging three measurements taken around the fruit equator, either in mesocarp and endocarp. Color was longitudinally determined on two points of each fruit[17].

Soluble solids content (SSC %), titratable acidity (TA %) and SSC: TA ratio (%): Fruit juice was extracted by homogenising fruit flesh in a blender. Soluble solid content was measured for each fruit with a digital refractometer (Atago, PR 32, Japan) and express in percentage. Total acidity content (expressed as Malic acid) was determined by titrating 5 ml juice with 0.1 N sodium hydroxide using phenolphthalein as an indicator, the TSS: TA ratio was determined. Methods as described by[16].

Ascorbic acid content (VC, mg/100 g fresh weight): was measured using 2, 6 dichlorophenol indophenols' method described by[16].

Total anthocyanins content (mg/100 g fresh weight): was measured colorimetrically at 535 nm in fruit skin according to the methods of[18].

Statistical analysis: The design for this experiment was a completely randomized design (CRD) with three replications. Data were analyzed with the analysis of variance (ANOVA) procedure of MSTATC program. Treatments means were compared by Duncan's multiple range tests at 5% level of probability in the average of two seasons of study[19].

Results and Discussions

CO_2 production: CO_2 production and O_2 uptake as an indicator of respiration rate were determined in Beauty and Japanese plum fruits, which harvested at different maturity stage as well as ripened for 7 days at 20ºC throughout the average of two seasons of study. There was a progressive significant increase in CO_2 production of both plum cultivars with expand the commercial maturities a well as after ripening during the two seasons of study as shown in Tables (1 and 2). At the 4*th* date of harvest, Beauty and Japanese plum fruits had the highest rate of CO_2 concentrations (7.33 and 7.87) as means of the two seasons respectively, compared with the lowest CO_2 production (2.80 and 2.20) recorded at the first date of plum fruit harvest.

On the other hand, O_2 uptake showed the opposite trend, which gave gradual and significant decrease as well as the harvest date increased, reached the least O_2 concentration (13.33 and 10.33) at the 4*th* date of harvest in the Beauty and Japanese plum fruits. Meanwhile, ripening plum fruits for 7 days appeared a progressive significant increase reached its maximum rate of O_2 concentration (20.53 and 19.27) in the Beauty and Japanese plum fruits previously harvested later (4*th* date). Most plum fruits are climacteric because they show autocatalytic ethylene production and a respiratory burst during ripening reported by[13]. The fruits reached the highest climacteric, while the highest respiratory rate also occurs, the aging process and death of fruits starts and the respiratory intensity decreases[20].

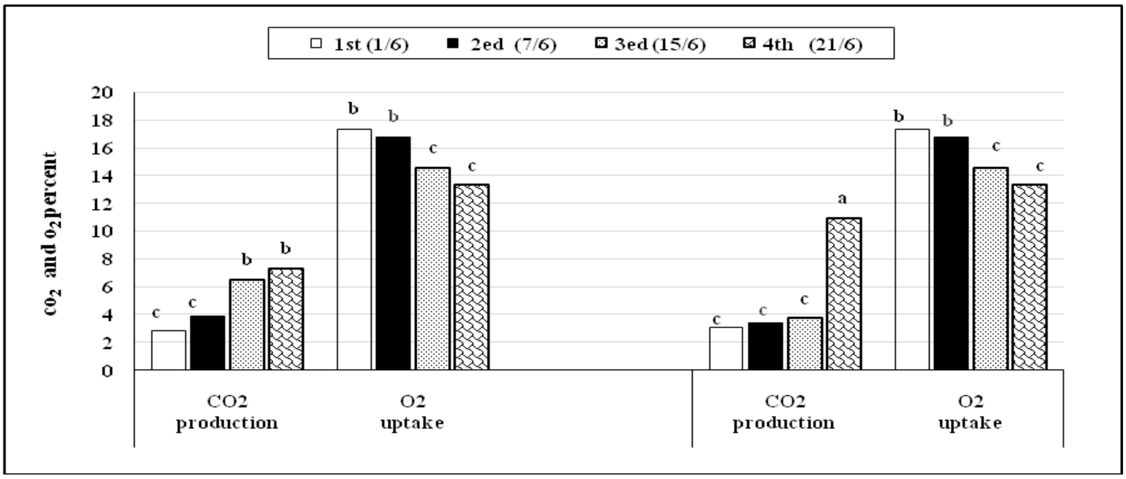


Fig. (1). CO_2 production and O_2 uptake of Beauty plum variety affected by different harvest dates and after ripening (average of two seasons).

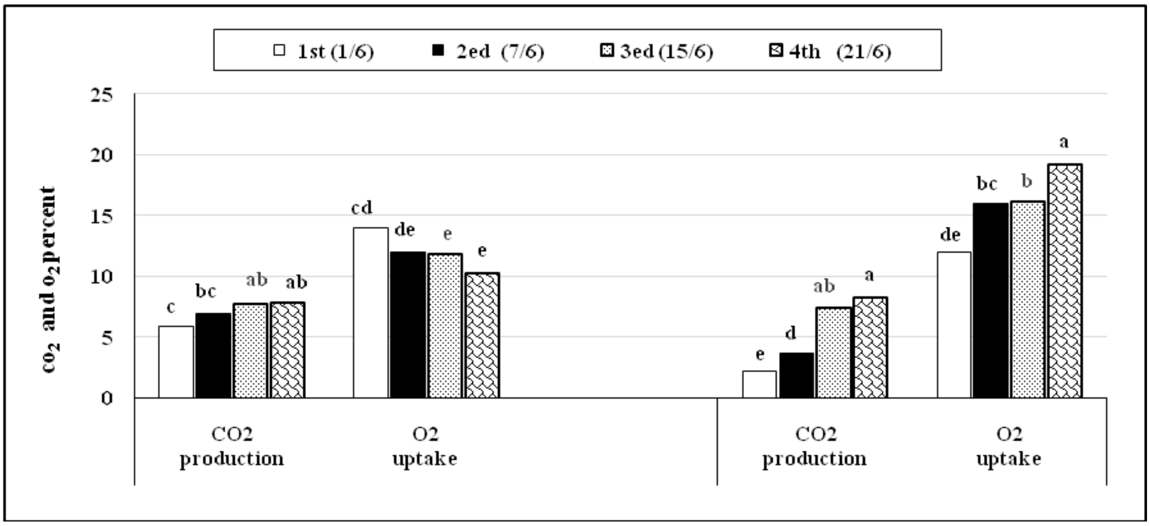


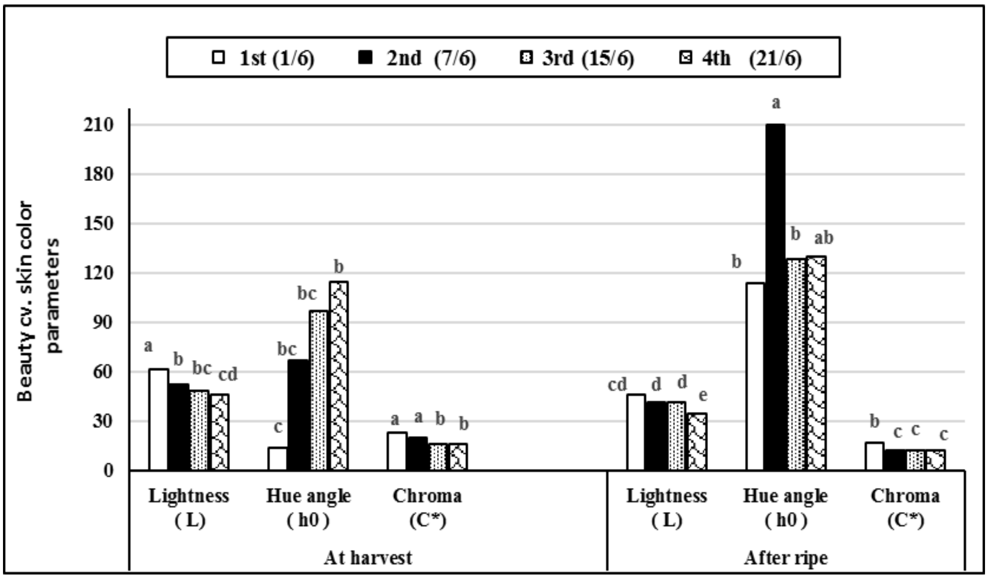
Fig. (2). CO_2 production and O_2 uptake of Japanese plum variety affected by different harvest dates and after ripening (average of two seasons).

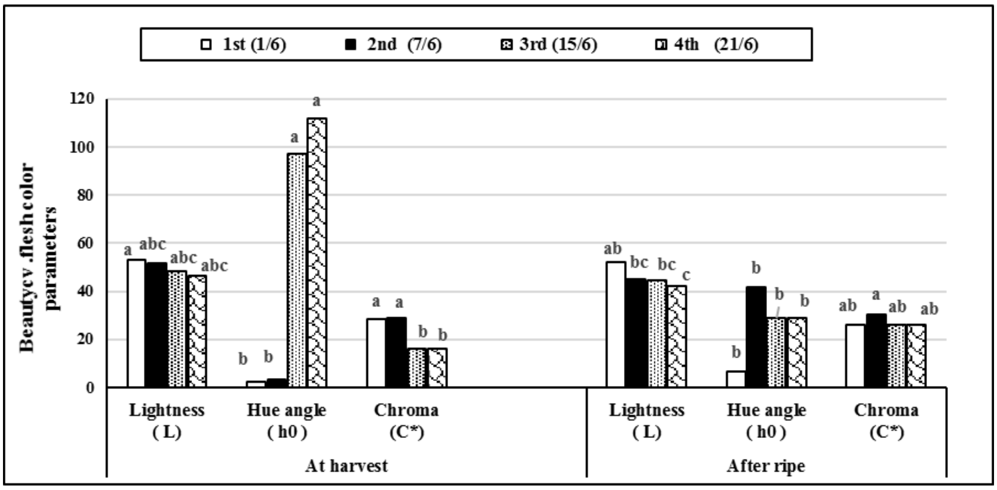
Fruit color: Plum fruit color is linked to the accumulation of carotenoids and anthocyanins. Both groups of pigments are more abundant in the peel but anthocyanins are mainly responsible for the surface color of the fruit[21]. Throughout color development, the plum color is expressed as color parameters; Lightness (L), Hue angle (h^o) and Chroma (C*) either in skin or/and flesh fruits harvested at different dates of maturity stage and after ripening at 20°C for 7 days. These color changes were significant and were correlated with visual color ratings during the average of the two successive seasons 2013 and 2014.

Lightness (L*): separates color into bright and dark and reflects L*. Plum fruits of Beauty and Japanese cultivars showed a slight and significant decrease of lightness with increasing the harvest dates and due to ripening at 20ºC for 7 days. The highest values of lightness (L*) of skin plum fruit (61.29 and 57.40) were recorded at the first harvest date of Beauty and Japanese cultivars respectively. While the least significant lightness (34.06) were revealed from delayed harvest of Beauty fruits (4^{th} harvest date). The same trend of lightness (L*) were observed in the peel of both cultivars of plum fruits.

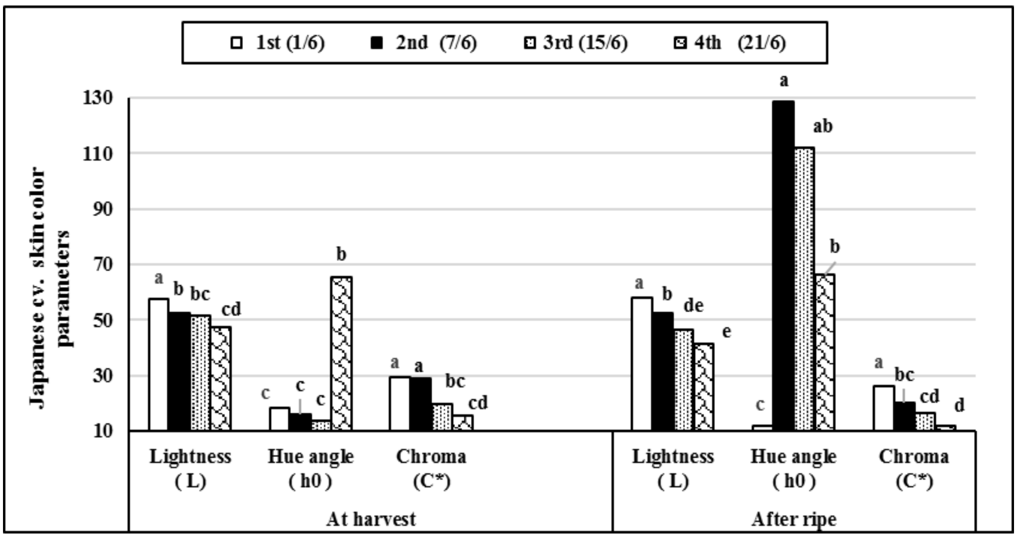
Hue angle (h^o): values is expresses the color and values are defined as follows: red-purple: 0; yellow: 90; bluish green: 180; blue: 270. The two plum cultivars recorded a significant and gradually greater increase with greater extend of harvest date and after ripening either in skin and peel plum fruits compared to the initial values during the two seasons. Meanwhile, a noticeable reduction of hue angle (h^o) was observed (66.47 and 9.96) in the skin and flesh Japanese cultivar respectively after ripening for 7 days of the late harvest date.

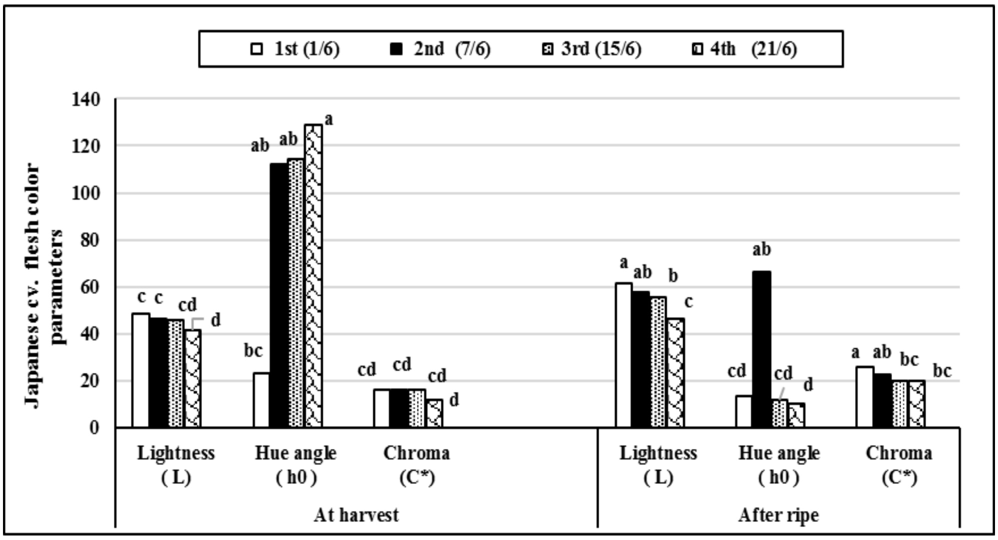
Chroma (C*): color parameter is a measure of color intensity or saturation with low values representing dull colors and high values representing vibrant colors. Chroma was appeared an significant reduction of skin fruit of both cultivars of plum as means of the two seasons of study, but with more higher values in Japanese variety than Beauty one. Moreover, peel color as measured by Chroma (C*) which changed from green to yellow progressed rapidly with significant increase for the first two dates of harvest and ripening, then showed an constant values throughout the other harvest and ripening dates in both cultivars of plum in the average of two seasons. The results are consistent with the findings in other cultivars of the European and Japanese plums harvested at different maturities[22]. In the other side, Diaz-Mula *et al*. (2009)[23] were found that hue angle values approaching (zero) in fruits with red skin color indicate an increase in red coloration.





Figs. (3 and 4). Skin and flesh color parameters of Beauty plum variety affected by different harvest dates and after ripening (average of two seasons).





Figs. (5 and 6). Skin and flesh color parameters of Japanese plum variety affected by different harvest dates and after ripening (average of two seasons).

Table (1). The effect of different harvest dates on the quality attributes of plum fruits cv. Beauty after ripe (average of two seasons).

Harvest dates	**Beauty variety**					
	Firmness (N)	**TSS (%)**	**Acidity (%)**	**TSS/Acid ratio (%)**	**Ascorbic acid (mg/100 g F.W.)**	**Anthocyanins content of skin (mg/100 g F.W.)**
At harvest						
1^{st} (1/6)	50.26 a	7.63 f	1.86 c	4.11 de	22.83 h	2.64 e
2^{nd} (7/6)	41.81 b	10.53 cd	1.81 c	5.84 c	27.17 g	5.68 d
3^{ed} (15/6)	34.1 bc	10.73 bcd	1.38 d	7.77 b	35.25 e	14.40 c
4^{th} (21/6)	18.98 ef	11.67 abc	1.08 d	10.95 a	29.11 f	33.64 a
After 7 days ripe						
1^{st} (1/6)	28.32 cd	8.50 ef	2.86 a	2.97 e	45.12 d	2.57 e
2^{nd} (7/6)	23.87 de	9.80 de	2.81 a	3.48 e	56.67 c	4.48 de
3^{ed}(15/6)	14.68 f	12.47 ab	2.53 ab	5.22 c	64.20 a	11.83 c
4^{th} (21/6)	14.53 f	13.40 a	2.31 b	5.39 c	59.41 b	23.48 b

Table (2). The effect of different harvest dates on the quality attributes of plum fruits cv. Japanese after ripe (average of two seasons).

Harvest dates	Japanese variety					
	Firmness (N)	**TSS (%)**	**Acidity (%)**	**TSS/Acid ratio (%)**	**Ascorbic acid (mg/100 g F.W.)**	**Anthocyanins content of skin (mg/100 g F.W.)**
At harvest						
1st (1/6)	73.84 a	6.93 b	3.71 a	1.87 c	24.17 e	3.61ef
2nd (7/6)	72.65 a	7.43 b	2.64 bc	2.81 c	36.50 d	5.06 e
3rd (15/6)	45.96 b	7.73 b	1.43 d	5.41 b	39.55 cd	17.30 c
4th (21/6)	34.55 c	8.13 b	0.86 e	9.42 a	37.67 d	31.53 a
After 7 days ripe						
1st (1/6)	47.59 b	7.67 b	3.06 b	2.51 c	46.50 c	2.83 f
2nd (7/6)	34.40 c	8.00 b	2.77 bc	2.89 c	55.00 b	5.04 e
3rd(15/6)	31.58 c	8.33 b	2.57 c	3.24 c	62.00 a	14.57 d
4th (21/6)	21.20 d	13.00 a	1.49 d	8.71 a	57.23 b	19.81 b

Fruit firmness (N):

Plums are climacteric fruit; they can be harvested when they are still firm but physiologically mature, which means they will continue to ripen after harvest and during the storage period. Fruit firmness is an excellent indicator of maximum maturity[24]. The decrease in fruit firmness is a physiological behavior occurring during maturation on the tree[25]. The fruit firmness decreased significantly during the harvesting period until the last harvest date and after holding for 7 days at room temperature (20ºC) for Beauty and Japanese varieties during the average of two seasons, as cleared in Tables (1 and 2).

The data cleared that, plum fruit harvested at an earlier maturity having the highest firmness (50.26 and 73.84 N) and after holding for 7 days at room temperature (20ºC) 28.32 and 43.59 N for the two varieties Beauty and Japanese respectively. Meanwhile, the latest maturity recorded the less fruit firmness (18.98, 34.55 and 14.53, 21.20 N). Statistically, the fruits of 'Japanese' were firmer than those of 'Beauty' variety. According to Peirs *et al*. (2000)[26], fruit picked too early stayed firmer over the whole storage period. Fruit firmness, which picked at the last harvest date, was 45% that of fruit picked at the first harvest. Firmness at harvest in all dates was lower than the typical levels at minimum maturity recommended by[27].

Soluble solid content (SSC):

Fruit SSC is a critical factor in determining fruit quality, and early-season plum cultivars are usually characterized by lower SSC than late-season plum cultivars. As fruit mature, the sugars become the main component of the soluble solids[6]. The results in Tables (1and 2) showed that the content of soluble solids increased gradually and significantly during different harvest dates until it reached the highest value in the last date for harvest (4*th* date) of both Japanese and Beauty varieties (8.13 and 11.67 %). After 7*th* day ripe at 20°C plum fruit clarified, an increase in soluble solids content reached the maximum percent at the last date for harvest. Meanwhile, Beauty variety showed the highest soluble solids percentage compared to Japanese variety.

These results are in accordance with the finding by (Crisosto, 1994)[24] who reported that soluble solids content (SSC) increases during plum fruit maturation and ripening. Crisosto *et al*. (2007)[27] reported that early cultivars have lower SSC than late ones in Californian plums this did not seem to occur in Spanish cultivars, since two late plums 'Larry Ann' and 'Songold' showed the minimum and the maximum SSC. Which ranged from 10-16 % in plum cultivars[7]. Singh *et al*. (2008)[28] studied the influence of harvest date and maturity stage on sugars and organic acid in early 'Blackamber', mid 'Amber Jewel' and late 'Angeleno' Japanese plum cultivars. They found that fructose was the major sugar followed by glucose, sorbitol and sucrose.

Total acidity (TA):

Fruit acidity plays a significant role in consumer acceptance, and for marketing, fruits acidity might be useful for increasing consumer satisfaction[4,27]. In general, malic acid is considered the predominant acid in plum fruits at maturity followed by shikimic and fumaric acid. There were significant differences in titratable acidity among different harvest dates and ripening at 20ºC as shown Tables (1 and 2). The highest significant content of titratable acidity was measured in Beauty plum fruit, followed by the lowest content in Japanese variety. The results showed that titratable acidity content was decreased significantly during the different harvest dates recorded the lowest content at the latest harvest date (1.08 and 0.86 %) for Japanese and Beauty varieties. Meanwhile, titratable acidity content of plum fruits ripening at 20ºC increased gradually and significantly reached the highest content at the latest harvest date (2.31 and 1.49 5%).

Unripe plum fruits are extremely acidic due to accumulation of many organic acids. Total acidity of fruit is directly influenced by the composition of different organic acids[29]. The taste of fruit acidity is not only dependent on the total acidity, but also on the type of organic acids, which play an important role in determining fruit acidity[30]. Ackermann *et al*. (1992)[31] and Crisosto *et al*. (2007)[27] suggested that malic acid declines during maturation and ripening in plum ,the decline in acidity is a result of a dilution effect due to the mass increase during the cell growth phase and a rise in respiration.

Ripening index (RI):

Ripening index (RI) measured as SSC/acid ratio and described as reliable parameter for fruit ripening. The influence of harvest dates and after 7*th* days ripening at 20ºC on RI ratio for both Japanese and Beauty varieties are shown in Tables (1 and 2). Ripening index (RI) SSC/TA ratio increased gradually and slightly significant during earlier harvest until the last harvest date as well as after ripening at room temperature 20ºC. The ratio was highly significant in last harvest dates in comparison to earlier harvest date for two varieties. Comparable results were obtained by Crisosto (1994)[24] who described the SSC/TA ratio as the most reliable parameter for plum ripening as this ratio increases during ripening and has a good relation with human perceptions of fruit quality. The ripening index (RI) as SSC/TA ratio has been considered to be a more reliable parameter for plum ripening than SSC or TA alone because the ratio increases during ripening[32, 22].

Ascorbic acid (AA):

Ascorbic acid is an important nutrient quality factors, which is very sensitive to degradation due to its oxidation compared to other nutrients during storage. The content of ascorbic acid increased significantly affected by different harvest dates and after 7*th* days ripe at 20ºC for both cultivars during the average of two seasons as shown in Tables (1 and 2). For both varieties, the data cleared that, plum fruit harvested at an earlier maturity recorded the lowest content of ascorbic acid (22.83 and 24.17 mg/100 g F.W.) and after holding for 7*th* days at room temperature (20ºC) 45.12 and 46.50. Meanwhile, the third harvest date reached the highest ascorbic acid content (35.25 and 39.55) and (64.20 and 62.00) after ripe then decreased at the latest harvest date. Generally, the fruits after ripe were higher ascorbic acid content comparing with different harvest dates, while Japanese fruits were higher content of ascorbic acid than those of Beauty cultivar. The ranges of total ascorbic acid (vitamin C) in mg/100 g F.W. were 5-14 (white-flesh nectarines), 6-8 (yellow-flesh nectarines), 6-9 (white-flesh peaches), 4-13 (yellow-flesh peaches), and 3-10 (plums) [33].

Total anthocyanin content (TAC):

The anthocyanins of skin plum fruit are the main phenolic compounds, especially red and purple cultivars[12]. The maturity at harvest had a marked effect on the total anthocyanins content in plum fruits, meanwhile, the accumulation of anthocyanins depends on the cultivar considered, with red-flesh plums having higher anthocyanin content[34]. In our study, the changes in total anthocyanin content during different maturation and after ripening at 20ºC for skin and flesh plum fruit for both varieties Japanese and Beauty are presented in Tables (1 and 2).

Anthocyanins content of skin plum fruit increased significantly during the harvesting period until the last harvest date and after 7*th* days ripe 20ºC for Japanese and Beauty varieties. There were significant differences in anthocyanins content of the skin plum fruit at the harvest dates; 1, 7, 15 and 21 days, generally, at harvest and after subsequently 7*th* days ripe at 20ºC, anthocyanins content increased gradually recorded the highest content at the late harvest dates, meanwhile the lowest content recorded at the earlier harvest dates. Plum fruits in Beauty cultivar having a higher anthocyanins content comparing with fruits Japanese ones.

These results agreed with Hui and Nip (2006)[35] who reported that the anthocyanin content in the fruit increases with maturity stages. The anthocyanin concentrations were higher in fruits of successive harvesting dates, meaning that anthocyanin accumulation seemed to occur constantly during fruit development and ripening[34]. On the other hand, Franke *et al.* (2004)[36] obtained quite lower anthocyanin content in *Prunus domestica* L. (4.5 - 11.3 mg/100 g F.W.), from the maturity stages HS_1 to HS_4 total anthocyanins increased by average 4.75 times.

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