

PHYSIO-CHEMICAL ASSESSMENT OF JUJUBE (*ZIZIPHUS MAURITIANA* L.) GENOTYPES AT THREE RIPENING STAGES GROWN UNDER CHOLISTAN DESERT, PAKISTAN

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ABSTRACT

Jujube belongs to the family “Rhamnaceae” is an evergreen plant having 170 species. It is a highly nutritious fruit crop riched in phenolic, antioxidant, and flavonoids. However, in Pakistan, it is considered a neglected crop with very little work performed and is growing in the Cholistan desert of Pakistan without any evaluation. This paper describes the physical and biochemical attributes of eight jujube genotypes (Anokee, Ajoba, Bahawalpur selection, Dilbahar, Dehli white, Karela, Mahmood wali and Gola) with its three stages (Unripe, Semi ripe and Fully ripe) growing in Cholistan dry and hot climatic conditions. The results revealed that these genotypes have significant variations in fruit traits such as fruit length, fruit width, and fruit weight during the ripening stages and the maximum increase in these parameters were observed at the fully ripe stage of jujube. Similarly, in biochemical analysis, TSS, total sugars, reducing and non-reducing sugars were increased with maturity and were highest at the fully ripe stage. Whereas, titratable acidity and ascorbic acid contents were decreased with maturity and were least at the final stage. However, total phenolic and flavonoids were highest at the semi-ripe stage. In physical evaluation, the genotypes “Gola”, “Mehmood wali” and “Dehli white performed better in the climatic conditions of Cholistan, Bahawalpur. While the genotypes “Dilbahar”, “Anokee”, “Karela” and “Bahawalpur selection” were enriched with phenolic and flavonoid contents.

Key words: genotypes, biochemical, attributes, ripening stages.

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INTRODUCTION

Jujube (*Ziziphus mauritiana* L.) is an evergreen plant that belongs to the family “Rhamnaceae” which consists of 50 genera and 170 species. The most prominent species of this family are *spina-christi*, *mucronata*, *nummularia*, *lotus*, *selata*, *spinosa*, *oenoplia*, *vulgaris*, *jujuba* and *mauritiana*. The fruit of this family is highly nutritious and cherished by people (Jackson *et al.*, 2011). The central origin of ber is Indo-Pak and Burma, where it is known as the poor man's fruit (Decandolle, 1986). In Pakistan, ber or jujube is widely growing in subtropical, dry, and arid zones. Its two prominent species of *Ziziphus* (i) *Ziziphus jujuba* M. and ii) *Ziziphus mauritiana* L.) are present in Pakistan. *Ziziphus jujuba* M. is recognized as the Chinese jujube whereas *Ziziphus mauritiana* L. is known as Indian jujube (Sharif *et al.*, 2019). This plant has the ability to grow on dry, saline and acidic soil (Dagar and Yadav, 2017).

Cholistan is the desert area of Pakistan which lies in the Southeast quadrant of the province Punjab, having its extension with Great Indian Desert, the Thar Desert in Sindh province of Pakistan, and with Rajasthan Desert of India (CDA, 2009). This area is an arid subtropical region having a high temperature, strong summer winds, high evapotranspiration, and low humidity with very little rainfall (PCRWR, 2018). Due to its high nutritional and medicinal value, it is considered as a “fruit of life”. In the Chinese medicine industry, it is highly recommended for the cure of different diseases like anemia, palpation, spleen deficiency, fever, diarrhea, and hypertoxicity (Akassh *et al.*, 2020). Moreover, it is a rich source of antioxidant compounds that have a positive effect on cardiovascular patient, cancer treatment, tumor patients, strengthening bones, protecting the liver, improving the weight gain, immune system, and streamlining blood circulation (Gao *et al.*, 2013). Along with fresh consumption, its byproducts like compotes, pickles, bread, cakes, alcoholic beverages, sweetened tea

syrup desserts, and chutneys are also used (Irshad *et al.*, 2020).

Fruits have been categorized based on their ripening process such as climacteric or non-climacteric (Almansa *et al.*, 2016). The process that causes the fruit to become more palatable is known as ripening. Fruit ripening is considered a part of the development changes which are activated by the essential hormones. Generally, the outcome of the ripened fruit is less green, softer and sweeter. In the ripening phase, the acidity decreases gradually without affecting its flavor (Fleuret and Macheix, 2003). Harvesting fruit at the suitable maturity stage not only expresses the quality of the fruit but also prevents quick perishability (Junior *et al.*, 2010). All the physiological, structural, and biochemical changes that happen in texture, flavor and color due to the ripening process are responsible for making the fruit more edible and delicious (Martel and Giovannoni, 2007).

Numerous other factors significantly affect the physicochemical characteristics of fruit, like soil nutrition, planting site, cultivating techniques, weather conditions and degree of ripeness. Besides, the genotype and fruit maturity stages play a key role in the alteration of fruit shape and biochemical qualities of fruits (Cordenunsi *et al.*, 2003), especially the anthocyanin and ascorbic acid contents of a cultivar vary with its maturity stages (Siddiqui, 2018). Harvesting of a product at its proper maturity stage is a key factor for its physicochemical quality attributes and for getting a high price in the local and international markets (Prasad *et al.*, 2018).

Jujube is a minor fruit crop and there is very little reported on jujube and its various ripening stages. Moreover, the quality attributes of jujube genotypes particularly growing in Cholistan (Bahawalpur), Pakistan is still unexplored. Therefore, the main objective of our study was to evaluate the physicochemical and nutritional characteristics of promising jujube genotypes along with the study of occurring physical and biochemical changes at its various maturity stages explicitly growing under Cholistan desert climatic conditions.

MATERIALS AND METHODS

Sample collection site and planting material: For physicochemical assessment of jujube, eight genotypes “Anokee”, “Ajoba”, “Dehli white”, “Bahawalpur selection”, “Karela”, “Mehmood wali”, “Dilbahar” and “Gola” were selected from a healthy orchard planted in the Regional Agriculture Research Institute (RARI) Bahawalpur (Cholistan), Punjab-Pakistan having 29°24' N latitude and 71°41' E longitude. The metrological data, including daily observations of minimum temperature, maximum temperature, rainfall, wind speed and relative humidity were recorded throughout the study period (Table 1). The fruits of the selected genotypes were

collected at different ripening stages of jujube i.e. unripe (UR), semi-ripe (SR) and fully ripe (FR). After fruit harvesting of each ripening stage, the fruit was packed in cardboard punnets and transported to the Laboratory of Pomology for physical and biochemical evaluation was performed in the Laboratory of Nano and Biomaterials, UAF under ambient conditions (25 ± 2 °C; 55-65 % RH).

Physical parameters: Regarding fruit quality, fruit parameters like color, texture, fruit shape, and stone shape were observed visually at each maturity stage as described by NBPGR (2002). While for quantitative traits, fruits parameters like fruit length (mm), fruit width (mm), stone length (mm), stone width (mm) were measured by using Digital Vernier Caliper (Model: HT0403A1, Cingda Industry Co., Ltd. China) whereas fruit weight (g) and stone weight (g) were recorded by using an electric balance (WT6002D, WANT Balance Instrument Co. Ltd., China).

Biochemical parameters

Total soluble solids (TSS): The total soluble solids (TSS) of jujube juice was determined through a digital refractometer (PAL-1, ATAGO, Japan) and its value was recorded in °Brix.

Pulp acidity (PA) and ascorbic acid contents (AC): Pulp acidity (PA) were determined by methodology as described in AOAC (2005) and it was expressed in percentage (%). While for the measurement of ascorbic acid contents (AA), the indophenol's titration was performed as proposed by Ruck (1963) and its results were expressed in mg per 100 g.

Total sugars (TS), reducing sugars (RS), non-reducing sugars (NRS): Total sugars (TS), Reducing sugars (RS), and Non reducing sugars (NRS) were determined by methodology as described in AOAC (2005).

Total flavonoid contents (TFC) & Total phenolic contents (TPC): The total flavonoid contents (TFC) were determined by AlCl₃ colorimetric assay as described by Zhishen *et al.* (1999) and expressed in mg CE 100 g⁻¹ FW. While the total phenolic contents (TPC) were analyzed by Folin-Ciocalteu reagent as described by Kujala *et al.* (2000) and values were expressed in mg GAE 100 g⁻¹ FW juice.

Antioxidant activity: It was determined from the tissues of the fruit by the 1,1-diphenyl-2-picryl hydrazyl (DPPH) method as described by Mensor *et al.* (2001). The percentage of DPPH scavenging activity was figured out by using the following formula:

$$A \quad a \quad (\%) \\ = 100 - \left[\frac{A - sc}{A - c_i} \right] \times 100$$

Data Analysis: For physical parameters evaluation, total nine jujube fruits were taken as individual replicates at

three ripening stages (unripe, semi-ripe and fully ripe) and total twenty seven fruits of each genotype were examined. While for biochemical analysis, twenty-five fruits were taken as single replicate that was cut down into small pieces and the juice was extracted to make the solution homogenized. Total three replications of each genotype was taken at individual ripening stage. The data collected was analyzed by using two-way variance analysis (ANOVA) under factorial Completely Randomized Design arrangements (ripening stages and genotypes) with three replications and analysis between the treatments was evaluated by using Tukey HSD test at $p < 0.05$ using the computer software Statistix Version 8.1® (Tallahassee Florida, USA) (Steel *et al.*, 1997).

RESULTS

Physical Characteristics: Jujube showed a significant variation in fruit physical characteristics relevant to different ripening stages and genotypes and there were huge variations observed in color and texture from the unripe to fully ripe stage (Table 2). The genotypes “Karela” and “Bahawalpur selection” changed their color from green at unripe to pink-red at the fully ripe stage while the remaining genotypes showed yellow to pale yellow color. Regarding fruit shapes, different fruit shapes were observed in the selected genotypes. In fruit shapes, genotypes “Ajoba”, “Mehmood wali” and “Dehli white” were roundish whereas genotypes “Anokee” and “Karela” were ovate and falcate respectively. While “Dilbahar” and “Bahawalpur selection” were having oblong and oblate shapes respectively. Generally, it was observed that roundish or oval-shaped fruits looked very nice, attractive and were liked by consumers. In this aspect, the genotypes “Ajoba”, “Mehmood wali,” “Dehli white” and “Gola” were very attractive. While regarding stone shapes, genotypes “Ajoba”, “Bahawalpur selection”, “Mehmood wali” and “Delhi white” were oval. “Anokee”, “Gola” and “Dilbahar” were oblong, while the “Karela” was the only genotype having club shape stones (Table 2). All these fruit and stone characters are the yield contributing characters for the improvement of jujube genotypes.

In observance of ripening stages and selected genotypes, maximum fruit length (FL) and fruit width (FW) was recorded in “Karela” (46.2 mm) and “Gola” (32.8 mm) at the fully ripe stage while the minimum was recorded in “Mehmood wali” (22.8 mm) and “Karela” (10.9 mm) at their unripe stage (Table 3). Similarly, fruit fresh weight greatly varied in the studied jujube genotypes during their maturity. The highest fruit weight was examined in genotype “Bahawalpur selection” at the fully ripe stage (26.37 g), while the lowest fruit fresh weight (2.15 g) was recorded in genotype “Karela” at its unripe stage.

The stone characteristics like stone length, stone width and stone weight of these jujube genotypes showed a significant difference from semi-ripe stage to fully ripe stage. The maximum stone length was observed in genotype “Anokee” (25.5 mm) at the fully ripe stage while, minimum in “Mehmood wali” (13.3 mm) at the unripe stage. Regarding stone width, it was highest in “Gola (9.7 mm) followed by “Mehmood wali” (9.7 mm), “Bahawalpur selection” (9.4 mm), “Dehli white” (9.2 mm), “Ajoba” (9.0 mm), “Anokee” (8.8 mm), “Dilbahar” (7.8 mm) and “Karela” (5.5 mm). While the highest stone weight was observed in genotype “Bahawalpur selection” (0.87 g) at the fully ripe stage. Whereas the least stone weight was observed in genotype “Karela” (0.12 g) at the unripe stage.

Biochemical Characteristics: In jujube genotypes, total soluble solids were increased from unripe to fully ripe fruit stage (6.85 to 18.55 °Brix) while the pulp acidity was decreased from unripe to fully ripe fruit stage in all genotypes (0.50 to 1.23 %) as shown in Table 4. Among the selected jujube genotypes, TSS was observed maximum in “Bahawalpur selection” (18.55 °Brix) at its fully ripe stage while it was (9.65 °Brix) at the unripe stage. Overall minimum TSS was observed in genotype “Karela” (6.85 °Brix) at its unripe stage. As the pulp acidity decreased from unripe to fully ripe stages in jujube genotypes, the maximum pulp acidity was observed in genotype “Ajoba” (1.33 %) at the unripe stage and it decreased to 1.23 % at the fully ripe stage. However, the lowest pulp acidity was observed in genotype “Mehmood wali” (0.42 %) at the fully ripe stage.

In sugars, total sugars (TS), reducing sugars (RS) and non-reducing sugars (NRS) contents were highly variable among the studied genotypes of jujube. The study revealed that total sugars (18.65 %) and non-reducing sugars (14.56 %) were highest in the genotype “Bahawalpur selection” at its fully ripe stage, while the fruit of “Karela” genotype showed the lowest sugars contents of total sugars (6.75 %), non-reducing sugars (5.49 %) and reducing sugars (4.05%) at its unripe stage. The increasing trend in total sugars was due to an increase in reducing sugars and non-reducing sugars resulting from the transformation of polysaccharides into sugars during growth and development. Among studied jujube genotypes, the ascorbic acid contents (AA) were maximum found in “Dilbahar” (50.84 mg/100g) at the unripe stage while the lowest was observed in “Mehmood wali” (17.15 mg/100g) at fully ripe stage. While TFC was in the range of 8.34-26.64 mg CAE/g FW (Table 4).

Phenolic and flavonoid compounds are secondary metabolites and are widely found in jujube fruit. It has multifunctional properties related to health benefits which are evolved directly to regular intake and bioavailability. TPC in jujube fruit ranged from 3.10-

11.54 (mg GAE/g FW) as shown in Fig 2. Individually, the highest TPC (11.54 mg GAE/g FW) was observed in genotype “Ajoba” at its semi-ripe stage.

Similarly, the highest TFC contents (26.64 mg CAE/g FW) were also observed at the semi-ripe stage of the “Dilbahar” genotype. The results of the antioxidant

activity of the eight jujube genotypes with their three ripening stages were shown in (Fig 1). Among selected genotypes, the genotype “Karela” had shown its highest antioxidant ability (99.31%), followed by “Dilbahar” (97.41%) and “Ajoba” (95.42%), while the genotype “Gola” has shown its least antioxidant ability (87.05%).

Table 1: Meteorological data including minimum, maximum temperature, average precipitation, average humidity and wind speed recorded in Cholistan (Bahawalpur), Pakistan during 2018.

Months	Mean Maximum Temperature (°C)	Mean Minimum Temperature (°C)	Average Precipitation (mm)	Average Humidity (%)	Wind Speed (KT)
January	21.84	6.50	0.00	65.53	1.22
February	26.18	11.15	0.09	62.25	1.87
March	32.36	17.04	0.00	58.30	1.77
April	37.95	21.68	0.09	40.59	1.51
May	39.33	25.48	0.25	40.69	2.72
June	41.03	28.28	0.61	49.01	2.90
July	38.10	27.41	1.83	56.59	2.80
August	37.76	27.64	0.36	61.73	1.87
September	36.55	24.74	0.00	60.58	1.83
October	33.76	18.48	0.00	57.16	1.43
November	28.39	12.71	0.00	58.91	0.83
December	23.16	7.50	0.07	63.05	0.86
<i>Mean</i>	33.03	19.05	0.27	56.19	1.80

Source: Weather Research Station Cholistan (Bahawalpur), Pakistan

Table 2: Phenotypic qualitative variation observed in eight jujube genotypes growing in Cholistan (Bahawalpur) at three ripening stages.

Genotypes	Ripening stages						Fruit shape	Stone shape
	Unripe		Semi ripe		Fully ripe			
	Colour	Texture	Colour	Texture	Colour	Texture		
Anokee	Dark green	Hard	Light green	Semi-hard	Yellow-green	Semi-soft	Ovate	Oblong
Ajoba	Light green	Semi-hard	Yellow-green	Semi-soft	Light yellow	Soft	Round	Oval
Gola	Dark green	Hard	Yellow-green	Semi-hard	Yellow	Soft	Oval	Oblong
Dehli white	Yellow-green	Semi-hard	Light yellow	Semi-soft	Yellow	Semi-soft	Round	Oval
Dilbahar	Light green	Semi-hard	Light yellow	Semi-soft	Yellow	Soft	Oblong	Oblong
Karela	Light green	Hard	Yellow	Semi-soft	Pink-red	Soft	Falcate	Club
Mehmood wali	Dark green	Hard	Light yellow	Semi-soft	Yellow	Soft	Round	Oval
Bahawalpur selection	Dark green	Hard	Yellow-green	Semi-soft	Pink-red	Soft	Oblate	Oval

Table 3: Agronomic quantitative characteristics of eight jujube genotypes growing in Cholistan (Bahawalpur) at three ripening stages.

Variables	Ripening	Genotypes							
	Stages	Ajoba	Anokee	Bahawalpur selection	Karela	Gola	Mehmood wali	Dilbahar	Dehli white
Fruit length (mm)	Unripe	24.27 ± 0.13 jk	26.60 ± 0.62 ij	23.87 ± 1.02 jk	26.05 ± 2.16 ij	24.67 ± 1.38 jk	22.81 ± 1.29 k	26.67 ± 1.36 ij	22.95 ± 1.26 k
	Semi ripe	30.45 ± 1.97 gh	33.55 ± 0.72 d-f	30.83 ± 1.45 f-h	34.84 ± 2.43 de	33.11 ± 0.97 e-g	34.52 ± 1.40 de	33.29 ± 0.14 e-g	28.66 ± 1.55 hi
	Fully ripe	31.11 ± 0.85 f-h	41.6 ± 1.80 b	39.25 ± 1.53 bc	46.29 ± 2.60 a	39.69 ± 2.03 b	39.42 ± 3.21 b	41.35 ± 1.19 b	36.40 ± 1.81 cd
Fruit width (mm)	Unripe	17.72 ± 0.12 ef	14.89 ± 1.14 gh	15.82 ± 0.94 e-h	10.95 ± 0.93 i	16.32 ± 0.88 e-g	13.59 ± 0.61 hi	15.15 ± 1.38 f-h	15.28 ± 1.33 f-h
	Semi ripe	23.23 ± 1.61 d	22.72 ± 1.53 d	24.21 ± 1.53 d	18.46 ± 2.43 e	28.29 ± 1.18 c	22.90 ± 1.78 d	22.72 ± 1.02 d	24.69 ± 0.92 d
	Fully ripe	28.00 ± 1.63 c	27.97 ± 1.13 c	30.01 ± 1.75 bc	25.25 ± 0.72 d	32.89 ± 2.16 a	31.32 ± 3.47 ab	28.13 ± 1.49 c	32.39 ± 1.44 ab
Fruit weight (g)	Unripe	4.71 ± 0.62 hi	3.85 ± 0.49 i	3.69 ± 0.47 i	2.15 ± 0.41 i	4.20 ± 0.44 hi	2.54 ± 0.30 i	3.92 ± 0.77 i	3.63 ± 0.60 i
	Semi ripe	10.95 ± 1.63 fg	10.06 ± 1.56 fg	10.83 ± 1.37 fg	7.56 ± 2.54 gh	15.31 ± 1.33 e	10.90 ± 1.68 fg	10.53 ± 0.76 fg	11.29 ± 1.12 f
	Fully ripe	16.00 ± 1.76 de	19.99 ± 2.21 bc	20.64 ± 3.00 bc	17.20 ± 1.44 c-e	26.37 ± 4.17 a	23.21 ± 5.75 ab	19.35 ± 2.40 cd	23.41 ± 2.08 ab
Stone length (mm)	Unripe	15.27 ± 1.10 f-h	20.98 ± 1.57 bc	16.67 ± 0.72 e-g	19.01 ± 2.15 c-e	19.68 ± 1.26 cd	13.31 ± 2.80 h	19.00 ± 2.14 c-e	17.80 ± 1.27 d-f
	Semi ripe	15.23 ± 0.72 f-h	24.07 ± 1.26 a	20.53 ± 1.42 c	23.22 ± 2.12 ab	19.68 ± 1.24 cd	14.12 ± 1.10 gh	21.18 ± 1.27 bc	19.16 ± 1.03 c-e
	Fully ripe	21.03 ± 1.46 bc	25.56 ± 1.12 a	20.81 ± 1.78 bc	23.39 ± 1.88 ab	19.90 ± 1.60 cd	20.39 ± 1.42 cd	21.24 ± 1.07 bc	19.76 ± 1.34 cd
Stone width (mm)	Unripe	8.55 ± 0.66 c-e	7.58 ± 0.35 e-g	7.76 ± 0.64 d-f	4.71 ± 0.67 i	8.60 ± 1.01 b-e	7.20 ± 0.57 fg	6.55 ± 0.72 gh	6.93 ± 0.49 fg
	Semi ripe	8.75 ± 0.13 a-e	8.58 ± 0.86 b-e	9.01 ± 0.61 a-c	5.58 ± 0.37 hi	9.43 ± 0.98 a-c	7.79 ± 0.56 d-f	7.33 ± 0.45 fg	8.58 ± 0.58 b-e
	Fully ripe	9.04 ± 0.62 a-c	8.82 ± 0.37 a-d	9.4 ± 0.70 a-c	5.50 ± 0.50 hi	9.77 ± 0.42 a	9.70 ± 0.92 ab	7.85 ± 0.16 d-f	9.20 ± 0.44 a-c
Stone weight (g)	Unripe	0.45 ± 0.82 g-j	0.52 ± 0.11 f-h	0.36 ± 0.11 h-j	0.12 ± 0.05 k	0.50 ± 1.02 g-i	0.28 ± 0.06 jk	0.32 ± 0.09 ij	0.25 ± 0.09 jk
	Semi ripe	0.56 ± 0.07 d-g	0.78 ± 0.96 a-c	0.72 ± 0.12 a-e	0.32 ± 0.05 ij	0.78 ± 0.15 a-c	0.45 ± 0.08 g-j	0.54 ± 0.09 e-h	0.64 ± 0.17 b-g
	Fully ripe	0.70 ± 1.62 a-f	0.81 ± 0.08 ab	0.87 ± 0.14 a	0.35 ± 0.11 h-j	0.86 ± 0.08 a	0.74 ± 0.21 a-d	0.59 ± 0.06 c-g	0.76 ± 0.11 a-c

Mean values followed by different letters within a row are significantly different at $p \leq 0.05$ by Tukey HSD test.

Table 4: Biochemical characteristics of eight jujube genotypes growing in Cholistan (Bahawalpur) at three ripening stages.

Variables	Ripening Stages	Genotypes							
		Anokee	Ajoba	Dilbahar	Dehli white	Bahawalpur Selection	Karela	Mehmood wali	Gola
Total soluble solids (°Brix)	Unripe	10.05 ± 0.05 m	9.85 ± 0.07 mn	8.75 ± 0.05 o	8.25 ± 0.03 p	9.65 ± 0.08 n	6.85 ± 0.02 q	10.75 ± 0.03 l	8.55 ± 0.05 o
	Semi ripe	12.35 ± 0.04 j	11.95 ± 0.44 k	10.05 ± 0.07 m	9.95 ± 0.98 m	10.95 ± 0.06 l	12.85 ± 1.20 i	16.75 ± 1.07 d	13.55 ± 0.66 h
	Fully ripe	17.75 ± 0.77 b	16.95 ± 1.02 d	14.55 ± 0.87 g	15.15 ± 0.76 f	18.55 ± 0.57 a	14.75 ± 0.25 g	17.25 ± 0.98 c	15.55 ± 0.28 e
Pulp acidity (%)	Unripe	0.66 ± 0.01 i	1.33 ± 0.02 a	1.08 ± 0.04 d	0.59 ± 0.05 k	0.62 ± 0.12 j	0.91 ± 0.05 f	0.50 ± 0.03 n	0.58 ± 0.04 k
	Semi ripe	0.59 ± 0.02 k	1.27 ± 0.05 b	1.01 ± 0.05 e	0.52 ± 0.04 l-n	0.53 ± 0.05 lm	0.86 ± 0.08 g	0.47 ± 0.02 o	0.54 ± 0.22 l
	Fully ripe	0.53 ± 0.12 lm	1.23 ± 0.23 c	0.93 ± 0.02 f	0.47 ± 0.22 o	0.51 ± 0.16 mn	0.82 ± 0.26 h	0.42 ± 0.02 p	0.50 ± 0.34 n
Reducing sugars (%)	Unripe	3.19 ± 0.07 e-i	3.37 ± 0.26 d-i	3.24 ± 0.42 d-i	3.02 ± 0.19 f-i	2.95 ± 0.28 hi	2.70 ± 0.02 i	3.01 ± 0.02 g-i	3.39 ± 0.38 d-i
	Semi ripe	3.83 ± 0.06 d-g	3.92 ± 0.03 c-e	4.05 ± 0.03 b-d	3.68 ± 0.33 d-h	3.90 ± 0.02 -e	3.86 ± 0.61 d-f	3.48 ± 0.44 d-i	3.74 ± 0.24 d-h
	Fully ripe	5.49 ± 0.59 a	5.01 ± 0.34 a	4.73 ± 0.26 a-c	4.86 ± 0.57 ab	4.08 ± 0.58 b-d	4.97 ± 0.44 a	5.38 ± 0.48 a	5.01 ± 0.56 a
Non-reducing sugars (%)	Unripe	7.06 ± 0.12 ij	6.17 ± 0.22 k	6.00 ± 0.36 kl	5.32 ± 0.25 l	4.19 ± 0.25 m	4.05 ± 0.06 m	6.34 ± 0.07 jk	5.25 ± 0.32 l
	Semi ripe	8.51 ± 0.11 fg	8.32 ± 0.07 fg	6.46 ± 0.02 jk	8.16 ± 0.28 gh	6.69 ± 0.04 i-k	7.38 ± 0.98 hi	9.06 ± 0.77 ef	7.47 ± 0.66 hi
	Fully ripe	11.75 ± 0.34 b	12.43 ± 1.23 b	9.81 ± 0.27 de	10.16 ± 1.12 d	14.56 ± 1.20 a	9.04 ± 0.76 ef	10.52 ± 0.78 cd	10.96 ± 0.28 c
Total sugars (%)	Unripe	10.25 ± 0.05 l	9.55 ± 0.04 m	9.25 ± 0.03 n	8.35 ± 0.05 p	7.15 ± 0.02 q	6.75 ± 0.05 r	9.35 ± 0.05 mn	8.65 ± 0.04 o
	Semi ripe	12.35 ± 0.08 gh	12.25 ± 0.05 h	10.51 ± 0.01 k	11.84 ± 0.02 i	10.59 ± 0.06 k	11.24 ± 0.05 j	12.54 ± 0.55g	11.21 ± 1.02 j
	Fully ripe	17.25 ± 0.22 b	17.45 ± 0.79 b	14.55 ± 0.40 e	15.02 ± 1.76 d	18.65 ± 0.76 a	14.01 ± 1.02 f	15.90 ± 0.28 c	15.97 ± 0.35 c
Ascorbic acid contents (mg/100 mL juice)	Unripe	48.10 ± 0.10 ab	41.77 ± 0.03 a-e	50.84 ± 2.05 a	49.87 ± 5.26 a	45.16 ± 0.66 a-c	47.03 ± 0.25 ab	43.52 ± 0.06 a-d	47.19 ± 2.12 ab
	Semi ripe	30.88 ± 0.08 b-g	27.61 ± 0.02 c-g	38.13 ± 0.06 a-f	33.27 ± 3.66 a-g	29.08 ± 0.08 c-g	34.52 ± 0.06 a-g	28.67 ± 0.76 c-g	26.42 ± 2.96 d-g
	Fully ripe	23.51 ± 0.32 fg	21.64 ± 0.34 fg	28.84 ± 1.36 c-g	24.58 ± 2.88 e-g	20.87 ± 1.68 fg	21.23 ± 2.18 fg	17.15 ± 0.67 g	20.74 ± 0.25 fg
Total flavonoid contents (mg CAE/g FW)	Unripe	16.71 ± 0.01 ef	16.98 ± 0.66 e	18.48 ± 0.22 d	13.26 ± 0.11 hi	15.40 ± 1.09 fg	15.09 ± 1.09 g	11.19 ± 0.98 j-l	10.01 ± 1.12 lm
	Semi ripe	24.36 ± 0.22 b	22.19 ± 0.20 c	26.64 ± 0.27 a	21.48 ± 1.78 c	22.86 ± 2.34 c	22.06 ± 2.22 c	18.47 ± 0.99 d	17.55 ± 0.55de
	Fully ripe	12.48 ± 0.66 ij	10.83 ± 0.56 k-m	13.98 ± 0.88 gh	9.92 ± 0.98 lm	11.75 ± 1.22 jk	14.94 ± 0.14 g	8.34 ± 0.58 n	9.47 ± 0.28 mn

Mean values followed by different letters with in a row are significantly different at $p \leq 0.05$ by Tukey HSD test.

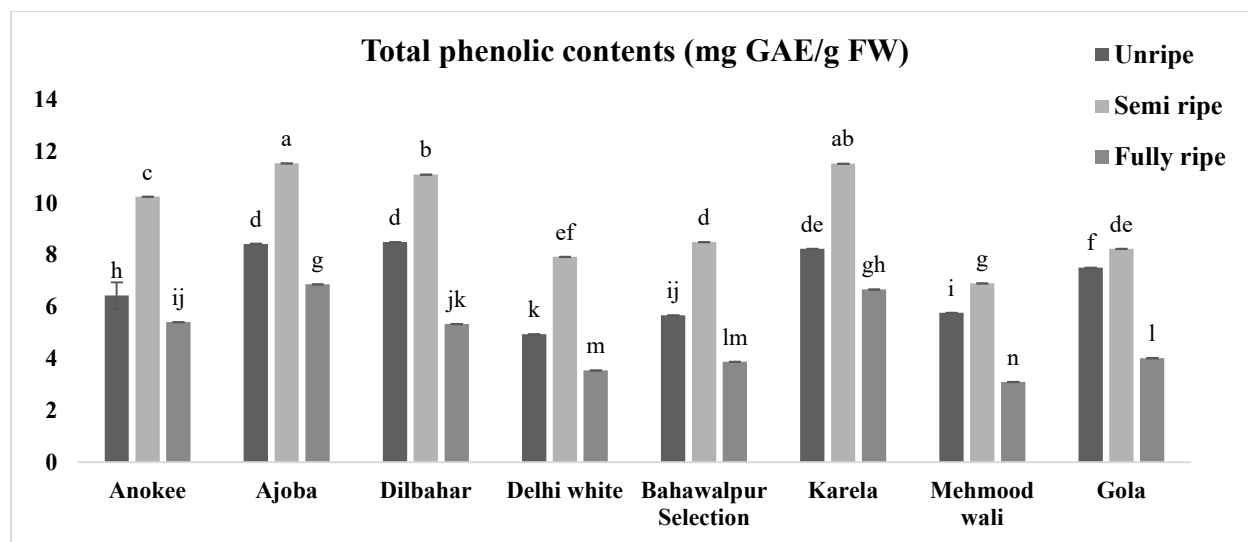


Figure 1. Variation observed in total phenolic contents of eight jujube genotypes growing in Cholistan (Bahawalpur) at three ripening stages

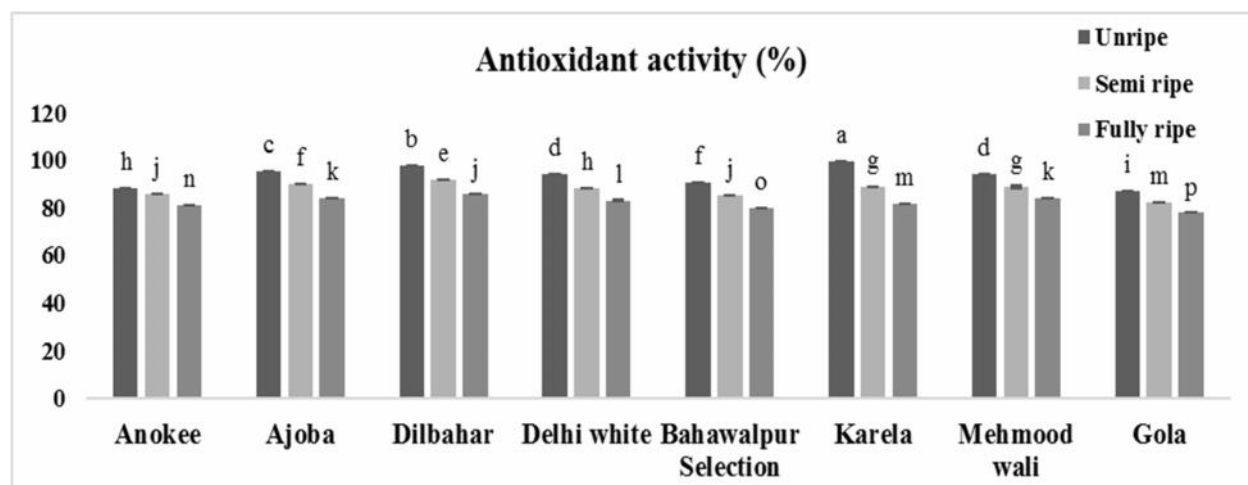


Figure 2. Variation observed in antioxidant activity of eight jujube genotypes growing in Cholistan (Bahawalpur) at three ripening stages.

DISCUSSION

The general physical appearance like its color, length, width and weight are important quality parameters that attract the consumer. These physical traits strongly depend upon the ecological climatic conditions and cultivars (Viyar *et al.*, 2017). Moreover, in varying climatic conditions genotype selection contributes its major role in maintaining fruit quality (Akram *et al.*, 2020). Cholistan is the desert area of Pakistan where the temperature normally remains high and dry. However, jujube is performing better in this area. In the assessment of jujube genotypes growing in Cholistan, all genotypes showed significant variation in fruit physical and biochemical attributes. In our findings, genotypes showed ovate, round, oval, falcate and oblate fruit shapes. This

character is related to the genotype and is less affected by climatic conditions. Similar findings were discussed by Obeed *et al.* (2006) who stated that jujube fruit is drupe and variability in fruit shape character (round to elongate) is cultivar specific. Traits related to fruit length, fruit width, stone length and stone width are economically very important and are targeted by jujube breeders and growers to increase the yield. In our study, the least fruit length (22.8 mm) was observed at the unripe stage in genotype “Mehmood wali” while its highest length (39.4 cm) was observed at the fully mature stage. Overall maximum fruit length (46.2 cm) was observed in “Karela” genotype. The reason for the difference in fruit length is the maturity stage and the genotype. As the fruit was not fully mature, the growth development of cells was not fully completed so its length was less in the

unripe stage. It also indicates that the stone of fruit was also not properly developed as the genotype “Mehmood wali” stone length was also least at its unripe stage. Moreover, the difference in fruit length at the fully ripe stage was varietal. Similar findings were reported by Karnatovska *et al.* (2007) who found fruit length range (13-32.2 mm) during the evaluation of 23 Chinese jujube varieties. Brindza *et al.* (2011) also determined the varied fruit length (16.7-21.6 mm) in jujube. In our findings, the stone weight was in range from 0.25-0.87 g. Our values were following Sivakov *et al.* (1988) who reported the means of stone weight in six *Ziziphus jujuba* Mill. genotypes were 0.28 to 0.65 g. All the physical fruit and stone characters are the yield contributing characters for the improvement of pulp yield in jujube. These are most important for breeders to improve the existing crop (Akram *et al.*, 2020).

In biochemical attributes, TSS increased in jujube fruit during unripe (6.85 °Brix) to fully ripe stage (18.55 °Brix). It increases during berry growth due to the synthesis of water-soluble contents and hydrolysis of polysaccharides into sugar. Yadav (2009) found the similar trend of increase in sugar during the growth and development of peventi jujube (*Ziziphus mauritiana* L.). Moreover, similar findings were observed by Jawanda and Bal (1980) who reported an increase in TSS towards ripening in various jujube genotypes. It also varies with different factors such as climatic conditions, soil type and management strategies of an orchard (Cao *et al.*, 2015). As TSS increases TA decreases as both are vice versa. Similar in this study, TSS increases with the ripening stages while TA decreases. It decreases from 1.33-0.42 % at the full ripe stage. Similar was reported by Teotia *et al.* (1964) that acid contents in jujube cv “Bansasi Karka” were found high at fruit set stage which indicates the accumulation of acid during the initial period. Our findings were also in harmony with Bal and Chohan (1981) who stated that acidity decreases gradually in jujube cultivars “Umran” and “Sanaura-2” during the growth and development of fruit.

Ascorbic acid contents change with sunlight exposure and growing conditions (Franke *et al.*, 2004). It acts as a chelating and reducing agent with the ability to scavenge free radicals. It is a key component of defense mechanisms and increases immunity. It has a similar trend to acidity as it is an acid and it gradually decreases with ripening. In our finding maximum ascorbic acid contents 50.84 (mg/100 mL juice) was observed in the “Dilbahar” genotype at the unripe stage while the least value (17.15 g) was observed in “Mehmood wali” at its fully ripe stage. Our results are in harmony with Bastos *et al.* (2016) who found a decrease in ascorbic acid contents in jujube during ber maturation. Similar least contents of ascorbic acid were observed in ber at 70 DAA (Nyanga *et al.*, 2013). Neves *et al.* (2008) stated that ascorbic acid decreases with maturation. Moreover, senescence is

responsible for the decrease of ascorbic acid contents. Similar findings were observed in guava (Pinto *et al.*, 2009).

The sugar contents greatly vary with maturation stage, genotype, soil topography, climatic conditions, and cultural practices. Hence, it is essential to check variation in sugars in particular genotypes growing in particular regions (Akram *et al.*, 2019). In the present study, overall all sugars including TS, RS and NRS had increased from unripe to fully ripe stage. However, there was less increase in RS during maturity as compared to NRS and TS. The less increase in reducing sugar contents is due to its energy consumption during the metabolic process of fruit development. This statement is also confirmed by Hammond and White (2008) who stated that degraded sugar helps in the tissue growth of a cell. Moreover, sugar contents are specified with the locality, environmental conditions, and management practices. The cultivars growing in hot weather are sweeter as compared to cultivars growing in the cool region (Akram *et al.*, 2020). Similar findings were observed by Hulme (1971) and Marsh *et al.* (2000) who stated that sugar contents are affected by different geographical regions and management practices.

Phenolic and flavonoid compounds are secondary metabolites widely found in jujube fruit. These metabolites help in preventing oxidative stress, chronic diseases, and inhibition of platelet aggregation. In our study, flavonoids and phenolic contents were maximum at a semi-ripe stage of jujube. Both contents showed a gradual increase in the first two ripening stages (unripe and semi-ripe stages) and then decreased in the ripe stage. Our findings are in line with Zozio *et al.* (2014) who stated that phenolic compounds are concentrated in the jujube during the first and second stages of maturation but it becomes less concentrated at the final stage of maturation. The results are also in harmony with the findings of Choi *et al.* (2012) who stated that total phenolic and flavonoids contents rapidly decreased when jujube changes its color from yellow to red at maturity. A similar trend was observed by Wang *et al.* (2013). DPPH or antioxidant activity is also an important reagent for evaluating the ability of phenolic compounds. The gradual decreases were observed in antioxidant activity from unripe to fully ripe stage. Moreover, each genotype has specific antioxidant activities. Kalt (2005) and Ozgen *et al.* (2008) stated that antioxidant activity is exaggerated by genotype, maturity stage of fruit, growing conditions, and characteristics of the fruit. Similar findings were examined by other researchers (Canan *et al.*, 2016; Saridas *et al.*, 2016; Pellegrini *et al.*, 2007).

Conclusions: Based on the physicochemical analysis, it is stated that jujube grown in Cholistan, Pakistan has the potential to grow commercially in this area. The results also showed that the jujube genotypes growing in

Cholistan have a significant difference in physiological traits. TSS, total sugars, reducing and non-reducing sugars were found maximum at the fully ripe stage of jujube. Whereas, maximum phenolic and flavonoids contents were observed at the semi-ripe stage of all jujube cultivars. The genotypes “Dilbahar”, “Anokee”, “Karela” and “Bahawalpur selection” were rich in phenolic and flavonoid contents. In yield related attributes, the genotypes “Gola”, “Mehmood wali” and “Dehli white” performed better in the climatic conditions of Cholistan, Bahawalpur and the physicochemical characteristics observed in the study will also be helpful for future breeding.

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REFERENCES

- Akassh, M., Fathima, T. and K. Mruthunjaya (2020). Health Promoting Effects of *Ziziphus mauritiana*: An overview. Int. J. Research in Pharm. Sci. 11(1): 1067-1072.
- Akram, M.T., R.W.K. Qadri, M.J. Jaskani and F.S. Awan (2019). Ampelographic and genetic characterization of grapes genotypes collected from Potohar region of Pakistan. Pak. J. Agri. Sci. 56(3): 595-605.
- Akram, M.T., R.W.K. Qadri, M.J. Jaskani and F.S. Awan (2020). Phenological and physicochemical evaluation of table grapes germplasm growing under arid subtropical climate of Pakistan. Pak. J. Bot. [http://dx.doi.org/10.30848/PJB2020-3\(7\)](http://dx.doi.org/10.30848/PJB2020-3(7))
- Almansa, S., F. Hernandez, P. Legua, M. Nicolas-Almansa and A. Amoros (2016). Physicochemical and physiological changes during fruit development and on-tree ripening of two Spanish jujube cultivars (*Ziziphus jujuba* Mill.). J. Sci. Food Agric. 96: 4098-4105.
- AOAC. (2005). Official Methods of Analysis, 18th edn. Association of Official Analytical Chemists, Washington, DC.
- Bal, J.S. and G.S. Chohan (1981). Fixation of maturity standards for ber cv. Umran. Punjab Horticult. J. 3: 70-73.
- Bastos, V.J., L.C. Neves, P.M.C.D. Silva, M. Shahab, R.C. Colombo and S.R. Roberto (2016). Harvest point determination of Indian jujube fruit (*Ziziphus mauritiana* L.) based on physicochemical and functional parameters. Sci. Horti. 213: 392-402.
- Brindza, J., M. Karnatovska, O. Grygorieva, V. Vietoris, L. Kucelova and G. Erdelyova (2011). Morphological and organoleptic nature of *Ziziphus jujuba* Mill. Potr. S. J. F. Sci. 5: 1-11.
- Canan, I., M. Gundogdu, M. Seday, U. Oluk, C.A. Karasahin, Z. Eroglu, E.C. Yazici and E. Unlu (2016). Determination of antioxidant, total phenolic, total carotenoid, lycopene, ascorbic acid, and sugar contents of Citrus species and mandarin hybrids. Turk. J. Agric. For. 40: 894-899.
- Cao, K., Y. Chang, R. Sun, F. Shen, T. Wu, Y. Wang, X. Zhang and Z. Han (2015). Candidate gene prediction via quantitative trait locus analysis of fruit shape index traits in apple. Euphytica. 206: 381-391.
- CDA. (2009). Facts Sheet about Cholistan. Cholistan Development Authority, CDA, Bahawalpur, Pakistan.
- Choi, S. J. Ahn, H. Kim, N. Im, N. Kozukue, C.E. Levin and M. Friedman (2012). Changes in free amino acid, protein, flavonoids, and phenolic content in jujube (*Ziziphus jujube*) fruit during eight stages of growth and antioxidative and cancer cell inhibitory effects by extracts. J. Agr. Food Chem. 60: 10245-10255.
- Cordenunsi, B.R., J.R. Oliveira-Do-Nascimento and F.M. Lajolo (2003). Physico-chemical changes related to quality of five strawberry fruit cultivars during cool-storage. Food Chem. 83: 167-173.
- Dagar, J.C. and R.K. Yadav (2017). Climate Resilient Approaches for Enhancing Productivity of Saline Agriculture. JSSWQ. 9(1): 9-29.
- Decandolle, A. (1986). Origin of cultivated plants. Bibliotheque Scientifique Interantionale; (Paris). 385 p
- Fleuret, A. and J.J. Macheix (2003). Phenolic acids in fruits and vegetables. CRC Press; New York (USA). 1-42 p
- Franke, A.A., L.J. Custer C. Arkaki and S.P. Murphy (2004). Vitamin C and flavonoid levels of fruits

- and vegetables consumed in Hawaii. *J. Food Compos. Anal.* 17: 1-35.
- Gao, Q.H., C.S. Wu and M. Wang (2013). The jujube (*Ziziphus jujuba* Mill.) fruit: A review of current knowledge of fruit composition and health benefits. *J. Agr. Food Chem.* 61: 3351-3363.
- Hammond, J.P. and P.J. White (2008). Sucrose transport in the phloem: integrating root responses to phosphorus starvation. *J. Exp. Bot.* 59: 93-109.
- Hulme, A.C. (1971). *The biochemistry of fruits and their products.* Academic Press; London (England). 537-554 p
- Irshad, Z., M.A. Hanif, M.A. Ayub, A. Hanif and H.I. Afridi (2020). Medicinal Plants of South Asia. *Novel Sources for Drug Discovery*; 451-463 p
- Jackson, D.I., N.E. Looney, M.M. Buker and G.F. Thiele (2011). *Miscellaneous fruit crops.* 3rd Ed. Cambridge University Press; Cambridge (UK). 280-293 p
- Jawanda, J.S. and J.S. Bal (1980). A comparative study on growth and development of ZG-2 and Kaithali cultivars of ber. *Punjab Hortic. J.* 20: 41-46.
- Junior, E.R.D., G. Goto, D.S. Rodrigues, M. Viventini and A.J.D. Campos (2010). Yellow pepper fruit quality and post-harvest conservation submitted at two harvest stage and package use. *Rev. Cienc. Agron.* 17: 23-30.
- Kalt, W. (2005). Effects of production and processing factors on major fruit and vegetable antioxidants. *J. Food Sci.* 70: 11-19.
- Karnatovska, M., J. Brindza, O. Grygorieva, V. Derevjanko, Z. Kochanova and D. Birova (2007). Jujube fruit (*Ziziphus jujuba* Mill.) variability determination. 1st International Scientific Conference on Medicinal, Aromatic and Spice Plants. *Book of Scientific Papers and Abstracts*, December 5-6, 2007, (Nitra). 219 p
- Kujala, T.S., J.M. Lopenen, K.D. Kalika and K. Pihlaja (2000). Phenolics and betacyanins in red beetroot (*Beta vulgaris*): Distribution and effect of cold storage on the content of total phenolics and three individual compounds. *J. Agric. Food Chem.* 48: 5388-5342.
- Marsh, K.B., A.C. Richardson and Y. Erner (2000). Effect of environmental conditions and horticultural practices on citric acid content. *Proceeding of the 9th International Citrus Congress*, FL, International Society of Citriculture, (Orlando). 640-643 p
- Martel, M. and J. Giovannoni (2007). *Fruit ripening, Plant Cell Separation and Adhesion*, Blackwell Publishing Ltd.; 164-76 p
- Mensor, L.I., F.S. Menezes, G.G. Leitao, A.S. Reis, T. Santos, C.S. Coube and S.G. Leitao (2001). Screening of Brazilian plant extracts for antioxidant activity by the use of DPPH free radical method. *Phytother. Res.* 15: 127-130.
- NBPGR. (2002). *Minimal Descriptors of Agri-Horticultural Crops (Fruit Crops).* New Delhi (India). 41-48 p
- Neves, L.C., R.M. Benedette, V. X. Silva, R.L. Vieites and S.R. Roberto (2008). Cold weather in Tahiti sour cherries, harvested at different times and submitted to thermal and biochemical treatments. *Magazine Brazilian fruit production.* 30: 377-384.
- Nyanga, L.K., T.H. Gadaga, M.J.R. Nout, E.J. Smid, T. Boekhout and M.H. Zwietering (2013). Nutritive value of masau (*Ziziphus mauritiana*) fruits from Zambezi Valley in Zimbabwe. *J. Agric. Food Chem.* 138: 168-172.
- Obeed, R., M. Harhash and A. Abdel-Mawgood (2006). Fruit properties and genetic diversity of five ber (*Ziziphus mauritiana* Lamk) cultivars. *Pak. J. Bio. Sci.* 11(6): 888-893.
- Ozgen, M., C. Durgac, S. Serce and C. Kaya (2008). Chemical and antioxidant properties of pomegranate cultivars grown in the Mediterranean region of Turkey. *Food Chem.* 111: 703-706.
- PCRWR. (2018). Pakistan Council of Research in Water Resources, Regional centers. Retrieved January 15, 2018. from http://pcrwr.gov.pk/about.php?view_estab.
- Pellegrini, N., B. Colombi, S. Salvatore, O.V. Brenna, G. Galaverna, D. Del-Rio and F. Brighenti (2007). Evaluation of antioxidant capacity of some fruit and vegetable foods: Efficiency of extraction of a sequence of solvents. *J. Sci. Food Agri.* 87: 103-111.
- Pinto, P.M., A.P. Jacomino, F.C. Cavalini, L.C. Cunha and K.N. Inoue (2009). Harvest time and quality of Kumagai and Paluma guavas. *Rev. Bras. Frutic.* 40: 37-43.
- Prasad, K., S. Jacob and M.W. Siddiqui (2018). Fruit maturity, harvesting, and quality standards, in: Siddiqui, M.W. (Ed.), *Preharvest Modulation of Postharvest Fruit and Vegetable Quality*, Academia Press; United Kingdom. 41-69 p
- Ruck, J.A. (1963). *Chemical methods for analysis of fruit and vegetable products.* Department of Agriculture Research Station Sunderland (Canada). Publication No. 1154.
- Saridas, M.A. N.E. Kafkas, M. Zarifikhosroshahi, O. Bozhaydar and S.P. Kargi (2016). Quality traits of green plums (*Prunus cerasifera* Ehrh.) at different maturity stages. *Turk. J. Agric. For.* 40: 655-663.
- Sharif, N., M.J. Jaskani, S.A. Naqvi and F.S. Awan (2019). Exploitation of diversity in domesticated and wild ber (*Ziziphus mauritiana* Lam.)

- germplasm for conservation and breeding in Pakistan. *Sci. Hortic.* 249: 228-239.
- Siddiqui, M.W. (2018). *Preharvest Modulation of Postharvest Fruit and Vegetable Quality*, Academia Press; United Kingdom.
- Sivakov, L., D. Georgiev, B. Ristevski and Z. Mitreski (1988). Pomological and technological characteristics of Chinese jujube (*Ziziphus jujuba*) in Macedonia. *Jugoslovensko Vocarstvo* 22: 387-392.
- Steel, R.G.B., J.H. Torrie and D.A. Dickey (1997). *Principles and Procedures of Statistics: A Biometrical Approach*. 3rd ed. McGraw Hill Book Co; New York (USA).
- Teaotia, S.S. and R.S. Chauhan (1964). Flowering pollination fruit set and fruit drop studies in ber (*Zizyphus mauritiana* Lamk.) floral biology. *Punjab Horticult. J.* 3: 60-70.
- Viyar, A.H., R. Qadri, A. Iqbal, N. Nisar, I. Khan, M. Bashir and F. Shah (2017). Evaluation of unexplored pomegranate cultivars for physicochemical characteristics and antioxidant activity. *J. Food Sci. Technol.* 54: 2973-2979.
- Wang, C., D. Cheng, J. Cao and W. Jiang (2013). Antioxidant capacity and chemical constituents of Chinese jujube (*Ziziphus jujuba* Mill.) at different ripening stages. *Food Sci. Biotechnol.* 22: 639-644.
- Yadav, S.S. (2009). Studies on physico chemical changes during growth and development of Ber (*Zizyphus mauritiana* Lamk.) fruit cv. Pevedi. *Quarterly Research J. Anim. Plant Sci.* 24: 77.
- Zhishen, J., T. Mengcheng and W. Jianming (1999). The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. *Food Chem.* 64: 555-559.
- Zozio, S., A. Servent, O. Hubert, A. Hiol, D. Pallet, D. Mbeugie-A-Mbeugie (2014). Physicochemical and biochemical characterization of ripening in jujube (*Ziziphus mauritiana* Lamk.) fruits from two accessions grown in Guadeloupe. *Sci. Horti.* 75: 290-297.