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Original article

Fruit properties during the harvest period of eleven Indian jujube (*Ziziphus mauritiana* Lamk.) cultivars

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ABSTRACT

The geometric attributes and physical, mechanical, and chemical properties were determined for 11 Indian jujube (*Ziziphus mauritiana* Lamk.) cultivars grown in Saudi Arabia including Zaytoni, Kashmiri, Komethry, Um-Sulaem with spines, Toffahy, Um-Sulaem without spines, Abdel-Sattar, Pu-Yun, Pu-Pineau, seedy ber, and buddling ber. The geometric mean diameter, surface area, sphericity, and shape index of the fruits ranged from 20.61 to 42.48 mm, 1339.58–5666.92 mm^2, 71.39–96.80%, and 110.25–275.18%, respectively. The fruit physical properties, i e fruit weight, fruit volume, stone weight, flesh weight, true fruit density, and pulp-stone ratio varied from 4.71 to 39.02 g, 4.78 to 42.75 cm3, 0.11 to 2.35 g, 4.61 to 36.67 g,0.913 to 1.055 g/cm3, and 7.90 to 43.11, respectively. In addition, the mean color value of L*, a* and b* for the fruits ranged from 64.48 to 96.33, 2.65–4.05, and 6.32–84.36, respectively. The mechanical properties, including elastic range, bioyield force, modulus of elasticity, plastic range, and rupture force ranged from 2.31 to 8.86 mm, 21.64–325.77 N, 14.15–124.09 N/s, 0.83–3.45 mm, 56.42–364.21 N, and 107.77–480.91 N/s, respectively. The greatest rupture force belonged to the Pu-Pineau cultivar and the smallest belonged to the Um-Sulaem without spines cultivar at the horizontal orientation of both cultivars. The fruit chemical analysis values for total soluble solids, titratable acidity, total soluble solids/titratable acidity ratio, and vitamin C ranged from 13.43 to 23.55%, 0.48–1.27%, 14.24–39.85%, and 55.27–164.47 mg/100 g, respectively. The relevant data obtained for the 11 varieties of Indian jujube are valuable for developing and designing machines for processing operations, transportation, separating, packing, sorting, and harvesting. Additionally, the findings revealed considerable variation in chemical content, physical and mechanical characteristics among the tested cultivars.

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1. Introduction

Jujubes are adaptable fruit trees that grow in tropical and subtropical areas of the world. There are two major domesticated jujubes; *Ziziphus mauritiana* Lamk. (Indian jujube or ber), and *Ziziphus jujuba* Mill (Chinese jujube) (Pareek, 2001; Anjum et al., 2018). There is a considerable confusion between Indian and Chinese jujube. Indian jujube is a semi-deciduous tree and its fruiting branches are evergreen, on the other hand, Chinese jujube is a deciduous tree (Azam-Ali et al., 2006).

Although, Indian jujube is minor fruit, but it is considered one of the ancient fruit crops which have a high economic value in terms of medicinal properties, nutrition, serving as fodder for cattle and environmental protection (Akbolat et al., 2008; Krishna et al., 2014). The fruit of Indian jujube has well known variations in properties such as fruit shape, fruit size, fruit weight, mature fruit color, stone weight, and pulp/stone ratio as well as in quality attributes such as titratable acidity, soluble solid content, vitamins and ascorbic acid content (Singh et al.,2007;; Obeed et al., 2008; Krishna et al., 2014; Salmanizadeh et al., 2014; Islam et al., 2015; Pareek, 2017; Hossain, 2019; Mathangi and Maran, 2020).

The Indian jujube fruit quality is assessed *via* a combination of its visual appearance for marketing, ripeness (maturity), size, color, sugar, and solid content, which must all be considered for the

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consumer (Altuntas et al., 2015). However, more attention must be paid to the management of jujube Indian trees because their cultivation is adversely affected by social-ecological stressors and environmental conditions (Singh et al., 2020).

The fruit attributes of any agricultural product are vital valuable for the design of equipment for harvesting, transportation, handling, separating, packing, sorting, and processing into different items (Altuntaş et al., 2013; Fu et al., 2014; Rafiq et al., 2016). Any machinery system designed without taking these characteristics into consideration results in insufficient applications that reduce work effectiveness and increase product loss (Akbolat et al., 2008). Therefore, assessing the fruit characteristics of jujube fruits are a pre-requisite for the appropriate design and development of any equipment.

Fruit properties during harvest are the most important factor that determine postharvest -life and final quality of all horticultural commodities; therefore it is important to harvest fruits at the proper stage to insure quality that meet the consumer expectations to regulated the physiological and biochemical activities process postharvest changes and maintain quality during postharvest (Kader, 2005).

Based on a literature search, there is no complete study assessing the physical, chemical, and mechanical characteristics during the harvest period of Toffahy, Pu-yun Pu-Pineau, Zaytoni and Komethry cultivars (Abbas and Fandi, 2002; Obeed et al., 2008; Kassem et al., 2011; Al-Obeed, 2012; Omar et al., 2015), while the cultivars Kashmiri, Um-Sulaem with spines, Um-Sulaem without spines, Abdel-Sattar, seedy ber, and buddling ber are not studied yet. Thus, the present investigation aimed to clarify fruit physical characteristics, geometric attributes, chemical constituents and mechanical properties of 11 Indian jujube cultivars which are considered one of the most important cultivars grown successfully in Saudi Arabia to obtain new information about Indian jujube with superior traits in a high quality product with economical interest. Identifying Indian jujube fruit properties variations can help customers to choose the correct fruits for different uses and help in improving the postharvest -life, final quality and adding and maintaining fruit quality for better marketability.

2. Materials and methods

2.1. Collection of Indian jujube fruit samples

The present study was performed on the mature trees of 11 Indian jujube *(Ziziphus mauritiana* Lamk.) cultivars: Zaytoni (V1), Kashmiri (V2), Komethry (V3), Um-Sulaem with spines (V4), Toffahy (V5), Um-Sulaem without spines (V6), Abdel-Sattar (V7), Pu-yun (V8), Pu-Pineau (V9), seedy ber (V10), and buddling ber (V11) (Fig. 1). These cultivars were grown at the Agricultural Research farm at Dirab region, King Saud University, Riyadh, Saudi Arabia (GPS coordinates: 24°24′43.0″N latitude, 46°39′30.7″E). All the trees were budded on ber rootstock except for seedy ber. The trees were cultivated in sandy loam soil (14.88% clay, 27.22% silt and 57.90% sand) and received the same cultural practices as usual in each orchard. Three trees as uniform as possible were selected from each cultivar. The samples of 150 mature fruits were picked randomly from each tree and manually cleaned to remove all foreign materials; however, only mature fruits at the color-turning stage were hand-picked by a horticulture specialist during the March 2020 season and brought to the laboratory.

2.2. Indian jujube geometric attributes determination

Three perpendicular axes: the major diameter (D1), minor diameter (D2), and length (L) of a single fruit, as shown in Fig. 2,

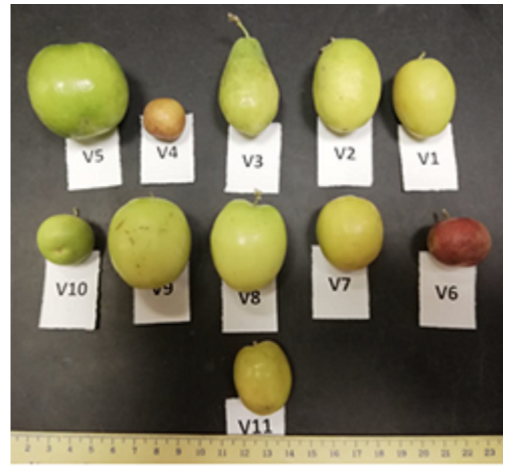

Fig. 1. The investigated Indian Jujube cultivars.

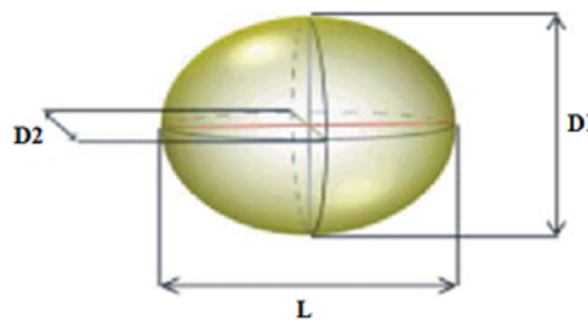

Fig. 2. Three perpendicular axes: length (L), major diameter (D1) and minor diameter (D2) of Indian Jujube.

were measured with the aid of a digital Vernier caliper (Mitutoyo, Japan) to an accuracy of 0.01 mm. These measurements were taken at the Fruit Laboratory located at the College of Food and Agriculture Sciences, King Saud University, Riyadh, Saudi Arabia. A total of 150 fruits of each cultivar were assessed.

The geometric mean of the fruit diameter (Dg, mm) was calculated using the following formula (Vivek et al., 2018):

$$Dg = (L \times D1 \times D2)^{\frac{1}{3}} \tag{1}$$

The sphericity index (φ, %) of the fruit was calculated using the following formula (Vivek et al., 2018):

$$\varphi = \frac{(Dg)^{\frac{1}{3}}}{L} \times 100 \tag{2}$$

The surface area (Sa, mm^2) was calculated as follows (Altuntas et al., 2018):

$$\mathrm{Sa} = \pi \times \mathrm{Dg}^2 \tag{3}$$

The shape of the jujube fruit is one of the main factors in sorting and classification associated with commercial quality (Morimoto et al., 2000). The shape index of the jujube fruit was calculated as follows (Singh et al., 2004):

$$JSI = \frac{L^2}{D1 \times D2} \times 100 \tag{4}$$

In which, JSI is the shape index of the jujube fruit and L, D1, and D2 are the length, major diameter, and minor diameter of the jujube fruit, respectively. The calculated shape index was compared with the recommended limits of common figures (JSI was considered round if it ranged from 100 to 160, oval if it ranged from 160 to 240, long if it ranged from 240 to 340, and very long when it is over 340, as reported by Singh et al. (2004).

2.3. Physical properties measurements

The same sample of each fresh Indian jujube fruit was weighed using an electronic weighing scale (Metler Toledo; the least count ± 0.001 g) according to the available method (Bastos et al., 2016). Weight was measured for the entire fruit, stone, and flesh. The pulp/stone ratio was calculated using the following formula (Mathangi and Maran, 2020). .

$$\text{Pulp/stone ratio} = \frac{(Fruit\ weight - Stone\ weight)}{Stone\ weight} \tag{5}$$

Fruit volume was measured by the water displacement method. True density (g/cm^3) was then calculated by dividing the fruit mass by the fruit volume. The determination of the moisture content wet basis of the Indian jujube fruits followed the standard method (AOAC, 2005). Briefly, after removing the stone from the fruits, they were kept in a drying oven at 60 °C (Pareek and Yahia, 2013). The weight difference before and after the drying process was used to determine the moisture content.

The skin color of the Indian jujube fruits was measured using a Minolta colorimeter (Konica Minolta, Model CR-400/410 Chroma Meters, Osaka, Japan) in terms of the L*, a*, and b* values. L*denotes lightness: 100white, 0black, a* denotes + red; −green and b* denotes + yellow, - blue (Itle and Kabelka, 2009). After initial calibration against a standard white surface plate, measurements were obtained (Reddy 2006). The color measurements of L*, a*, and b* were made in triplicate; however, each sample was scanned in different cylindrical coordinates Three fruits from each cultivar were used for measuring color values (Jat et al., 2013).

The chroma and hue angle are effective parameters for describing visual color appearance (Bernalte et al., 2003).Chroma represents color saturation, which varies from dull (low value) to vivid color (high value); and the hue angle is defined as a color wheel, with red–purple at an angle of 0°, yellow at an angle of 90°, bluish-green at an angle of 180°, and blue at an angle of 270° (McGuire, 1992).

$$C = \sqrt{(a*)^2 + (b*)^2} \tag{6}$$

when a* > 0 and b* > 0, the hue angle (α) is calculated as follows:

$$\alpha = \tan^{-1}\left(\frac{b*}{a*}\right) \tag{7}$$

when a* < 0 and b* > 0 (Lancaster et al., 1997), the hue angle (α) is calculated as follows:

$$\alpha = 180 + \tan^{-1}\left(\frac{b*}{a*}\right) \tag{8}$$

2.4. Mechanical properties determination

The force–deformation curve of the Indian jujube fruit under the compression test was investigated with a quasi-static loading device; this testing device obtained the mechanical properties for one compression axis (in line with the longitudinal) of the Indian jujube fruits. A texture analyzer (TA-HDi, Model HD3128, Stable Micro Systems, Surrey, UK) was used to perform the test. The testing device consists of a lower plate, upon which a single fruit is placed, and an upper plate that moves down at a fixed speed of 3 mm/min from an initial distance of 10 mm from the surface of the sample; the upper plate compresses the Indian jujube fruit between the two plates until it ruptures. The sensed force applied to the sample was transmitted to a computer by a load cell connected to a stationary upper plate; the force increased in response to the resistance of the sample. The texture analyzer was interfaced with a computer using Texture Expert Exceed software (version 2.05), which enables the textural data to be acquired and analyzed. All tests were conducted at room temperature (approximately 23 ± 1 °C). Before performing the test, the load cell, and probe distance of the instrument were calibrated using the methods and tools provided by the company. Four random individual fruits were utilized for the test. Different indicators were extracted from the force–deformation curves obtained from the compression test (Fig. 3). These included the modulus of elasticity (N/mm), which is defined as the slope of a straight line through a and P1; the bioyield force (P2; N); the elastic range (D_{P1}; mm); the rupture point (P3; N); the plastic range (D_{P2}; mm); and hardness, which is indicated by the area under P3 (N/mm).

2.5. Chemical properties

Chemical properties such as moisture content, titratable acidity, Total Soluble Solids) of juice, TSS/acidity ratio, and vitamin C were determined for the fresh Indian jujube fruits. Moisture content and titratable acidity (expressed as % citric acid) were determined according to the AOAC (2005). TSS was measured using a handheld refractometer (Atago Co. Tokyo, Japan) expressed as °Brix (Ranganna, 1986). The fruit maturity index, defined as the TSS/titratable acidity ratio, was calculated by dividing the TSS value by the titratable acidity of the juice. Ascorbic acid was determined using 2,6 dichlorophenol indophenol dye (Ranganna, 1986), except that 4% oxalic acid in 8% glacial acetic acid was used for sample extraction (Plummer, 1978).

2.6. Statistical analysis

All data were tested to assess the cultivar effects on the examined parameters using a one-way ANOVA. The means were separated and compared using the least significant difference (LSD) at the 0.05 level of probability. The statistical analysis was performed using SAS version 9.13. Correlation analysis among physical, mechanical, and chemical parameters in the studied Indian jujube fruit cultivars was examined by excel software and denoted by Pearson's correlation coefficient.

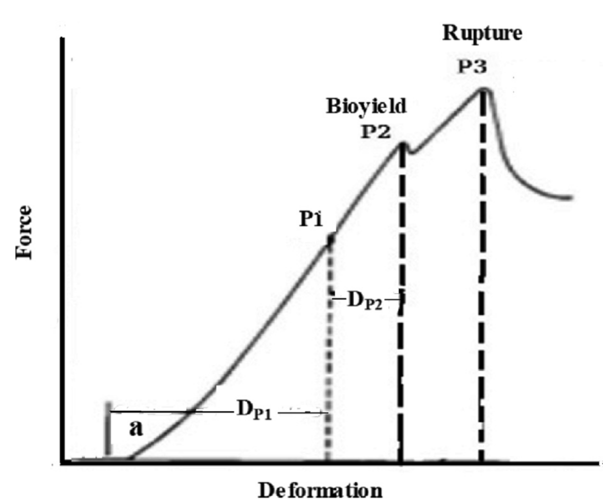

Fig. 3. Force-deformation curve of agricultural produce with demonstration of bioyield point (ASAE, 2008).

3. Results

3.1. Analysis of geometric attributes of Indian jujube fruits

The mean geometric attributes of the 11 Indian jujube fruit cultivars are shown in Table 1. All the geometric attributes were statistically significantly ($p < 0.05$) affected by the jujube cultivar.

In the present study, the length, minor diameter, major diameter, geometric mean diameter, surface area, sphericity, and aspect ratio of the 11 Indian jujube fruits ranged from 23.00 to 44.75 mm, 19.29 to 40.63 mm, 19.87 to 43.00 mm, 20.61 to 42.48 mm, 1339.6 to 5666.9 mm^2, 71.39 to 96.80%, and 0.61 to 0.98, respectively. The findings of Razi et al. (2013) showed that fruit length and diameter differed significantly ($p < 0.05$) among the 11 different cultivars. The maximum fruit length was observed in cv. Karela (4.69 cm). Pareek (2001) summarized the physical characteristics of Indian jujube cultivars in India, which displayed wide variations (fruit length ranged from 1.1 to 4.7 cm and size (length × breadth) ranged from 1.7 to 2.2 × 3.5–5.7). Saini et al. (1994) reported that the largest fruits (4.2 × 1.6 cm) were found in severely pruned trees and the smallest fruits (3.6 × 1.6 cm) were found in un-pruned trees. The surface area and sphericity index of the Indian jujube fruits were 926.28 mm^2 and 91%, respectively, as reported by Salmanizadeh et al. (2014). Kumari et al. (2015) studied eight ber cultivars under rainfed conditions of Jammu during 2013–2014. The maximum fruit weight (19.07 g), fruit length (49.68 mm), fruit breadth (29.81 mm), and fruit volume (17.50 cm^3) were recorded in Sanaur-4 cv., whereas the maximum specific gravity was recorded in Gola cv. (1.38).

Fig. 4 depicts the shape index value and corresponding shape for investigated Indian jujube fruits. The investigated Indian jujubes display one of three shapes: oval, long, or round; however, the round shape is predominant in the cultivars. Pareek (2001) reported that the ber fruit shape varied from round to oval, ovate, obovate, oblong, and oblate.

The fruit aspect ratio, which relates the fruit diameter to fruit length, has been considered an identifying feature for a cultivar (Cao et al., 2015; Kurian and Peter, 1997). In the present study, the Toffahy cv. possessed the largest aspect ratio (0.98), indicating that the shape of this cultivar was round, as shown in Fig. 4. The jujube fruit cultivar in this study with the smallest aspect ratio (0.61) was Komethry cv., which indicates that this cultivar has a long fruit shape, as shown in Fig. 4. In the study by Yildiz et al. (2015), the fresh golden berry fruit has a high aspect ratio of 0.988 and will roll rather than slide on their flat surfaces, similar to the jujube fruit (Akbolat et al., 2008). This tendency to either roll or slide is particularly important in the design of hoppers (Yildiz et al., 2015). The variance in aspect ratio indicates that the differences of the investigated cultivars are real. According to the characteristics of the fruit, jujube is considered a stone fruit. The fruit shape varies from round to oval to elliptical, the size varies from the size of a cherry to that of a plum, and some varieties can become larger than a chicken egg (Taiwan jujube varieties) (Markovski and Velkoska-Markovska, 2015). Mathangi and Maran (2020) reported a mean fruit weight (g) of 65.5 ± 5.4, a mean fruit height (cm) of 4.98 ± 0.22, a mean fruit diameter (cm) of 4.42 ± 0.16, a mean stone weight (g) of 7.1 ± 2.7, and a mean pulp-stone ratio of 7.3 ± 2.44 for a new ber called apple ber.

3.2. Analysis of the physical properties of Indian jujube fruits

The mean values for the measured and calculated physical properties of the 11 varieties of Indian jujube fruits are shown in Table 2. There were significant differences between all the physical fruit parameters of the 11 varieties.

The significant differences revealed that there is a significant variability among the cultivars for all the characteristics investigated. In the present study, the results showed that the fruit weight, fruit volume, stone weight, flesh weight, true fruit density, and pulp-stone ratio varied from 4.71 to 39.02 g, 4.78 to 42.75 cm^3, 0.11 to 2.35 g, 4.61 to 36.67 g,0.913 to 1.055 g/cm^3, and 7.90 to 43.11, respectively. Various researchers have stated variation among Indian jujube cultivars. Pareek (2001) reported that the fruit of Indian jujube cultivars weighed from 3.8 to 39.5 g. Kundu et al. (1995) noted the highest fruit weight (29.34 g) in Cantonment cv., whereas Lal Wali cv. had lowest fruit weight of 9.54 g. Kundi et al. (1989) recorded fruit weights ranging from 18.38 to 24.91 g in cv. Umran. Ghosh and Mathew (2002) found that the fruit weight, diameter and length were 39.2 g, 3.8 cm and 4.8 cm, respectively in cv. Umran. Razi et al. (2013) found that the fruit weight was as high as 23.4 g in cv. Umran and as low as 5.854 g in cv. Ghor, whereas the largest volume (24.75 cm^3) was reported in cv. Umran and the smallest (10.7 cm^3) in cv. Ghor. Islam et al. (2015) reported a fruit weight and fruit pulp-stone ratio of 24.33 g and 15.66, respectively, for BARI Kul-2 cv. Omar et al. (2015) reported that the fruit weight and flesh weight of jujube cv. Puyin under Saudi Arabia conditions were 13.28, 15.36 for fruit weight, 11.65, and 12.97 g for flesh weight for the2012 and 2013 seasons, respectively. Ghosh and Mathew (2002) found that the TSS, titratable acidity, TSS/titratable acidity ratio and vitamin C were 14.8%, 0.38%, 38.8 and 201.2 mg/100 g pulp, respectively in cv. Umran. Kassem et al. (2011) reported that for the Pu-Yun jujube cultivar, the average volume, flesh weight, stone weight, moisture content (%), TSS, titratable acidity, TSS/titratable acidity ratio, vita-

Table 1
Mean geometric attributes of Indian jujube fruits of investigated cultivars during the harvesting period.

Indian jujube cultivars	⁺Mean geometric attributes						
	Geometric mean diameter	Surface area	Sphericity index	Aspect ratio	Length	Minor diameter	Major diameter
	(mm)	(mm^2)	(%)	(– – –)	(mm)	(mm)	(mm)
Zaytoni	27.70^{f}	2409.6^{g}	84.89^{d}	0.7920^{e}	32.63^{e}	25.21^{f}	25.85^{f}
Kashmiri	34.95^{c}	3836.1^{d}	81.34^{d}	0.7420^{e}	42.97^{ba}	31.17^{d}	31.88^{d}
Komethry	31.94^{e}	3204.1^{f}	71.39^{e}	0.6147^{f}	44.75^{a}	26.50^{e}	27.49^{e}
Um-Sulaem with spines	20.61^{i}	1339.6^{i}	90.93^{c}	0.8811^{d}	23.00^{g}	19.29^{h}	19.87^{h}
Toffahy	42.48^{a}	5666.9^{a}	96.80^{a}	0.9799^{a}	43.89^{a}	40.63^{a}	43.00^{a}
Um-Sulaem without spines	23.61^{h}	1751.3^{h}	93.28^{bac}	0.9617^{ba}	25.32^{f}	21.37^{g}	24.35^{g}
Abdel-Sattar	32.92^{d}	3402.7^{e}	93.71^{bac}	0.919^{bdc}	35.13^{d}	31.45^{d}	32.29^{d}
Pu-yun	37.66^{b}	4454.4^{c}	91.21^{c}	0.8837^{d}	41.30^{bc}	35.46^{c}	36.49^{c}
Pu-Pineau	38.35^{b}	4618.1^{b}	96.05^{ba}	0.948^{bac}	39.93^{c}	37.31^{d}	37.85^{b}
Seedy ber	24.62^{g}	1903.8^{h}	90.71^{c}	0.9668^{ba}	27.15^{f}	20.96^{g}	26.24^{f}
Buddling ber	28.59^{f}	2566.2^{g}	91.77^{bc}	0.8911^{dc}	31.15^{e}	27.02^{e}	27.76^{e}
LSD (0.05)	0.93	159.5	4.42	0.0602	2.22	0.75	0.86

⁺ If the letters are the same, there is insignificant difference between different cultivars.

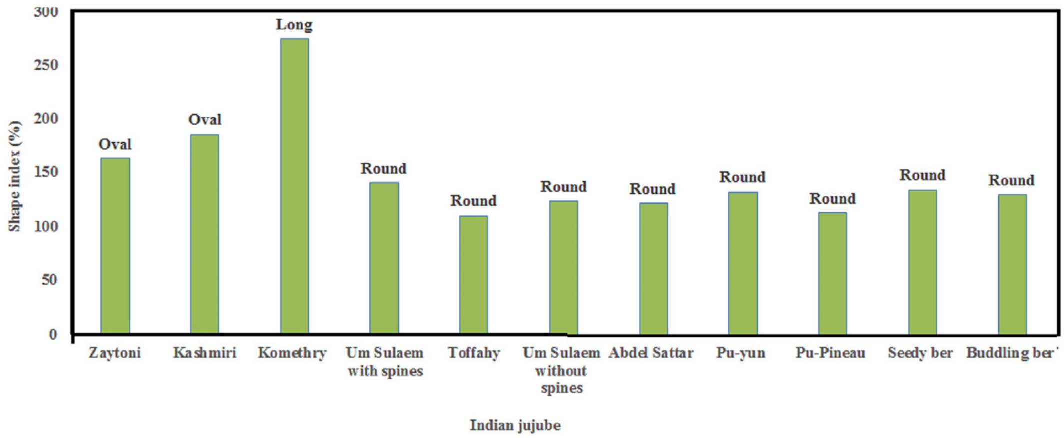

Fig. 4. Shape index value and corresponding shape for investigated Indian jujube fruits.

Table 2
Mean values for measured and calculated physical characteristics of the 11 varieties of Indian jujube fruits.

Indian jujube cultivars	+Mean values for measured and calculated physical characteristics					
	Fruit weight (g)	Fruit volume (cm^3)	Stone weight (g)	Flesh weight (g)	True fruit density (g/cm^3)	Pulp/stone ratio (−−−)
Zaytoni	11.62 g	12.18f	0.99f	10.63 g	0.954cb	10.72de
Kashmiri	22.35d	23.53d	0.98f	21.37d	0.949cb	21.83b
Komethry	16.82f	17.60e	1.38dc	15.45f	0.956cb	11.21d
Um-Sulaem with spines	4.71i	4.78 h	0.11 h	4.61i	0.987b	43.11a
Toffahy	39.02a	42.75a	2.35a	36.67a	0.913c	15.66c
Um-Sulaem without spines	6.80 h	7.00 g	0.16 h	6.65 h	0.971b	42.43a
Abdel-Sattar	18.72e	18.93e	1.33d	17.39e	0.989b	13.08dc
Pu-yun	28.76c	30.75c	1.88b	26.88c	0.935cb	14.34c
Pu-Pineau	31.89b	32.75b	1.43c	30.46b	0.973b	21.30b
Seedy ber	7.70 h	8.43 g	0.87 g	6.84 h	0.9160c	7.90e
Buddling ber	13.07 g	12.40f	1.17e	11.90 g	1.055a	10.18de
LSD (0.05)	1.49	1.47	0.09	1.43	0.055	3.01

+ If the letters are the same, there is insignificant difference between different cultivars.

min C, fruit length, and fruit width were18.33 ml, 16.56 g, 1.47 g, 78.1%, 14.5%, 0.44%, 35.2, 32.1%, 3.70 cm, and 3.27 cm, respectively, for the 2010 and 2011 seasons. Obeed et al. (2008) reported that the average fruit weight of Tofahy cv. was 31.72 and 31.32 g in the two seasons of 2005 and 2006, respectively.

Analysis of skin color parameters of Indian jujube fruits are shown in Table 3 cleared that the significant differences between means are indicated by letters near the mean. When the letters are the same, there is no significant difference between different cultivars. As shown in Table 3, the mean color values of L*, a*, and b* of the investigated Indian jujube fruits varied from 64.48 to 96.33, −2.65 to 4.05, and 6.32to 84.36, respectively.

Significant differences were noted in the chroma among the Indian jujube cultivars; the color chroma value varied from 6.86 to 90.55, with the highest value belonging to the Pu-Pineau cultivar and the lowest belonging to the Um-Sulaem with spines cultivar. In addition, a significant difference was found in the hue angle for the Indian jujube fruit cultivars, which varied from 65.92° to 113.02°; the highest value belonged to the Um-Sulaem with spines

Table 3
Mean values for skin color parameters of the 11 varieties of Indian jujube fruits.

Indian jujube cultivars	+Mean skin color parameters				
	L*(−−−)	a*(−−−)	b*(−−−)	Chroma(−−−)	Hue angle (Degree)
Zaytoni	78.24f	−15.96f	31.90e	35.72e	116.69a
Kashmiri	96.33a	−21.82 g	70.97c	74.25c	107.10dc
Komethry	86.11d	−16.56f	52.68d	55.26d	107.63dc
Um-Sulaem with spines	81.34e	−2.65b	6.32 g	6.86 g	113.02ba
Toffahy	64.48 h	−26.13 h	76.54b	80.88b	108.86bc
Um-Sulaem without spines	79.06fe	4.05a	9.09 g	9.99 g	65.92f
Abdel-Sattar	91.70c	−12.91e	52.89d	54.44d	103.72de
Pu-yun	92.99bc	−25.46 h	78.72b	82.74b	107.92dc
Pu-Pineau	74.49 g	−32.88i	84.36a	90.55a	111.30bc
Seedy ber	80.18fe	−6.14c	16.52f	17.67f	110.72bc
Buddling ber	95.79ba	−10.40d	54.27d	55.26d	100.85e
LSD (0.05)	3.1	1.62	4.01	3.84	4.26

+ If the letters are the same, there is insignificant difference between different cultivars.

cultivar and the lowest value belonged to the Um-Sulaem without spines cultivar.

The largest L* value belonged to the Kashmiri cultivar, and the smallest value belonged to the Toffahy cultivar. According to the study of Jat et al. (2013), the average L*, a*, b*, chroma, and hue angle values of the fruit skin of Indian jujube (*Ziziphus mauritiana* Lamk. cv. Gola) fruits at day 0 were 13.20, 0.83, 10.92, 10.95, and 87.38° respectively. As observed in Table (3), the mean value of L* presents slight variability among the cultivars and a* has no clear trend; meanwhile, b* fluctuates between the values of 6.32 and 84.36. The color parameters of the *Ziziphus jujube* Mill. fruits of the G.A.L. cultivar are 81.78, –5.56 and 19.59 for L*, a*, and b*, respectively; for the MSI cultivar, these values are 79.35, –7.19 and 21.82, respectively; and for P.S.I. cultivar, they are 78.88, -6.19 and 22.06, respectively (Wojdyło et al., 2019); all reported values are for fresh fruits.

The chroma value indicates the degree of color saturation and is proportional to the strength of the color (Urbonaviciene et al., 2012). A clear change was found in the chroma and hue angle among Indian jujube cultivars. These changes may be related to the fact that the Indian jujube (*Ziziphus mauritiana* Lamk.) demonstrates a rich biodiversity with respect to morphometric and fruit characteristics (Bhargava et al., 2005); additionally, the quality of Indian jujube fruits is adversely affected by various abiotic and biotic factors (Nallathamb et al., 2006). As explained by Cardenas-Perez et al. (2017) and Itle and Kabelka (2009), changes in L*, a*, and b* are related to increases in carotenoid levels and a loss of chlorophyll in the pericarp.

3.3. Mechanical properties

The mean fruit mechanical property values of the 11 varieties of Indian jujube fruits are shown in Table 4. In the present study, there were significant differences between all the fruit mechanical parameters of the 11 varieties. The elastic range, bioyield force, modules of elasticity, plastic range, rupture force, and work varied from 2.31 to 8.86 mm, 66.78 to 325.77 N, 14.15 to 124.09 N/s, 0.83 to 3.45 mm, 56.42 to 364.21 N, and 101.55 to 480.91 N/s, respectively.

The bioyield point depends on the mechanical resistance of the tissue (Błaszczak et al., 2004). This finding was in agreement with that of Ávila et al. (2007), who stated that the compressive bioyield point could be set as the maximum value that the curve could reach. The sudden decrease at this point indicates that the sample was fractured. The highest elastic range belonged to the Pu-Pineau cultivar and the lowest belonged to the Um-Sulaem without spines cultivar. The highest bioyield force belonged to the Pu-Pineau cultivar and the lowest belonged to the Um-Sulaem with spines cultivar. The highest modules of elasticity belonged to the Komethry cultivar and the lowest belonged to the seedy ber cultivar. The highest plastic range belonged to the Pu-yun cultivar and the lowest belonged to the Um-Sulaem with spines cultivar. The highest rupture force belonged to the Pu-Pineau cultivar and the lowest belonged to the Um-Sulaem without spines cultivar. The highest work value belonged to the Abdel-Sattar cultivar and the lowest belonged to the seedy ber cultivar.

The mechanical properties that promote fruit quality include thee elastic range, bioyield force, modules of elasticity, plastic range, rupture force, and work. In the present study, clear variations in mechanical properties appeared in the 11 investigated Indian jujube fruits. However, the mechanical properties of fruits are important for understanding their behavior in processing, storage, distribution, and consumption. The physical and mechanical properties of fruits are important design parameters for designing and fabricating equipment related to post-harvest processing (Ahmadi et al., 2009). The typical results of compression tests of biological materials initially begin with a linear curve with a slight inflection observed near the maxima in the curve. This pattern is related to the first cracks (Sadowska et al., 2005) that appear on the samples; many researchers have confirmed a close connection between mechanical properties and the microstructure of biological materials (Oey et al., 2007; Varela et al., 2007; Billy et al., 2008).

3.4. Chemical properties

The mean values for the chemical properties of the 11 varieties of Indian jujube fruits are shown in Table 5. There were significant differences between all the fruit chemical parameters of the 11 varieties. Moisture content has been considered a critical parameter to evaluate the quality of fresh Indian jujube fruits, and it can be significantly affected by genotype and cultivation conditions (Maraghni et al., 2011). The data given in Table 5 show that fruit moisture content varied from and 74.13 to 84.27% w.b.

On the other hand, the TSS, titratable acidity and the TSS/titratable acidity ratio ranged from 13.43 to 23.55%, 0.38 to 1.27% and 14.24 to 39.85%, respectively. Islam et al. (2015) reported that the TSS (%) and TSS/titratable acidity ratio of BARI Kul-2 were 15.60, and 39.72, respectively. Omar et al. (2015) reported that the TSS and titratable acidity of the jujube cv. Puyin under Saudi Arabia conditions were 12.47%, 11.09%, 0.75%, and 0.59% for the 2012 and 2013 seasons, respectively. The highest TSS value belonged to the Um-Sulaem without spines cultivar and the lowest belonged to the Toffahy and Pu-Pineau cultivars. The highest titratable acidity value belonged to the buddling ber cultivar and the

Table 4
Mean values for mechanical properties of the 11 varieties of Indian jujube fruits.

Indian jujube cultivars	[+]Mean mechanical properties					
	Elastic range	Bioyield force	Modules of elasticity	Plastic range	Rupture force	Work
	(mm)	(N)	(N/s)	(mm)	(N)	(N.s)
Zaytoni	4.71^{efg}	114.80^{de}	63.85^{ed}	1.88^{de}	150.68^{f}	293.19^{e}
Kashmiri	6.86^{cb}	186.98^{b}	73.36^{cd}	2.99^{bc}	210.67^{d}	377.31^{d}
Komethry	5.19^{ef}	159.83^{c}	124.09^{a}	4.13^{a}	246.78^{c}	426.23^{c}
Um-Sulaem with spines	4.58^{fg}	66.78^{f}	21.97^{gf}	0.83^{f}	83.44^{g}	175.22^{f}
Toffahy	3.72^{g}	112.98^{e}	84.69^{cb}	1.48^{fe}	190.29^{ed}	369.16^{d}
Um-Sulaem without spines	2.31^{h}	21.64^{g}	17.87^{gf}	2.40^{dc}	56.42^{h}	101.55^{g}
Abdel-Sattar	7.55^{b}	306.63^{a}	30.56^{f}	2.03^{de}	320.49^{b}	480.91^{b}
Pu-yun	6.32^{cd}	154.14^{c}	51.09^{e}	3.45^{ba}	178.95^{e}	304.15^{e}
Pu-Pineau	8.86^{a}	325.77^{a}	93.25^{b}	1.50^{fe}	364.21^{a}	778.25^{a}
Seedy ber	5.70^{ed}	76.63^{f}	14.15^{g}	0.90^{f}	82.56 g	107.77^{g}
Buddling ber	7.65^{b}	140.53^{dc}	21.89^{gf}	1.95^{de}	170.95^{ef}	261.99^{e}
LSD (0.05)	1.06	27.08	15.04	0.67	23.47	44.82

[+] If the letters are the same, there is insignificant difference between different cultivars.

Table 5
Mean values for chemical properties of the 11 varieties of Indian jujube fruits.

Indian jujube cultivars	[+]Mean chemical properties				
	Fruit moisture content	TSS	Titratable acidity	TSS/titratable acidity ratio	Vitamin C
	(% wb)	(%)	(%)	(%)	(mg/ 100 g)
Zaytoni	79.72[ed]	13.65 [h]	0.67[e]	20.39[ef]	67.11[f]
Kashmiri	81.95[c]	15.90[f]	0.49 [g]	32.51[b]	60.52 [g]
Komethry	80.37[d]	14.85 [g]	0.38 [h]	39.85[a]	86.84[d]
Um-Sulaem with spines	80.32[d]	19.43[c]	0.86[c]	22.60[ed]	55.27 [h]
Toffahy	80.16[d]	13.43 [h]	0.60[f]	22.30[ed]	72.37[e]
Um-Sulaem without spines	74.13 [g]	23.55[a]	0.83[d]	28.56[c]	87.33[d]
Abdel-Sattar	79.29[e]	18.75[d]	0.63[f]	29.80[c]	164.47[a]
Pu-yun	82.84[b]	14.85 [g]	0.61[f]	24.35[d]	56.58 [h]
Pu-Pineau	84.27[a]	13.43 [h]	0.48 [g]	28.03[c]	55.92 [h]
Seedy ber	74.41 [g]	21.15[b]	1.10[b]	19.32[f]	135.53[c]
Buddling ber	76.03f	18.08[e]	1.27[a]	14.24 [g]	151.32[b]
LSD (0.05)	0.82	0.28	0.031	2.22	3.17

[+] If the letters are the same, there is insignificant difference between different cultivars.

lowest belonged to the Komethry cultivar. The highest TSS/titratable acidity ratio belonged to the Komethry cultivar and the lowest belonged to the buddling ber cultivar. The highest vitamin C value belonged to the buddling ber cultivar and the lowest belonged to the Um-Sulaem with spines cultivar. The highest fruit moisture content belonged to the Pu-Pineau cultivar and the lowest belonged to the seedy ber cultivar.

Ascorbic acid is a critical antioxidant in fruits, and it has been reported to scavenge free radicals through inhibiting the radical chain reactions. Its accumulation in fruits is mainly determined by fruit genotype, cultivation condition, and management application (Chen et al., 2019). In the present study all cultivars were rich in vitamin C varied from 55.27 to 164.47 mg/100 g.

Mathangi and Maran (2020) reported a TSS(°Brix) of 8.4 ± 0.32, a titratable acidity (%) of 0.21 ± 0.05, a TSS/titratable acidity ratio of 30.1 ± 1.7, a vitamin C (mg) content of 64.6 ± 2.8, and a moisture content of 90.2% for a new ber called apple ber. Kumari et al. (2015) showed that the ber cultivars of Sanaur-4 recorded the maximum TSS (15.750 (°Brix) and TSS/titratable acidity ratio (40.38).

The chemical characteristics that promote fruit quality, which include TSS, titratable acidity, TSS/titratable acidity ratio, and vitamin C, showed clear variation in the 11 investigated Indian jujube cultivars. However, the increase in soluble solids during the period of fruit ripening may be due to the activity of the sucrose-phosphate synthase enzyme, which is an important enzyme in the biosynthesis of sugars (Hubbard et al., 1991). Moreover, increased TSS may be attributed to the conversion of starch into soluble solids. With the advancement of ripening, starch contents decrease progressively, while TSS increases (Sharma et al., 2008; Singh et al., 2015). In hot and arid ecosystems, most of the cultivars displayed an adequate TSS level, and the differences in the TSS value could be attributed to climatic variations in the area and generally dry weather favors that enhanced TSS in most of the cultivars (Shukla et al., 2007).

3.5. Correlation analysis

A correlation analysis was performed to investigate the correlations of the investigated physical, mechanical, and chemical parameters in the studied Indian jujube fruit cultivars (data not shown). High positive correlations appeared among fruit weight, fruit volume, and stone weight. Flesh weight was positively correlated with stone weight (r = 0.87). TSS was negatively correlated with fruit weight, fruit volume, stone weight, moisture content, and flesh weight (r = − 0.73, −0.73, −0.73, −0.79, and − 0.73, respectively). Chroma displayed high positive correlations with fruit weight, fruit volume, stone weight, moisture content, and flesh weight and a negative correlation (r = −0.78) with TSS content. Moreover, the rupture force was positively correlated with the chroma (r = 0.75). The geometric mean diameter was positively correlated with fruit weight, fruit volume, stone weight, moisture content, and flesh weight and negatively correlated with TSS. There was a high positive Pearson's correlation coefficient between fruit length and diameter (r = 0.7333) that indicated a spontaneous and simultaneous increase or decrease in fruit length and diameter (Razi et al., 2013). The surface area had the highest positive correlation with fruit weight, fruit volume, stone weight, moisture content, flesh weight, and geometric mean diameter; it was also negatively correlated with TSS. Finally, the aspect ratio had the highest positive correlation (r = 0.97) with the sphericity index.

4. Discussion

Farm production can be significantly increased through the use of mechanical technologies that are both labor saving and yield increasing. Such technological interventions are commonly referred to as agricultural mechanization; therefore, a judicious choice is crucial for farmers to achieve optimum profitability. The choice can also have a major impact on the environment; only the use of those with a positive environmental effect can be sustainable over the long term. It is therefore important to identify the appropriate related properties of fruits, vegetables, and seeds (Houmy et al., 2013). Thus, the full mechanization of crops in agricultural systems is an important goal that can be achieved through the utilization of the physical, chemical, and mechanical properties of crops and the careful management of farm machinery of agricultural inputs, particularly for Indian jujube trees. In the present study, different characteristics of the quality attributes of 11 Indian jujube fruits were considered and were shown to differ significantly from one another (Tables 1, 2, 3, 4, and 5). The variation among cultivars in regard to the average fruit weight might be due to genotype, inherent characteristics, and climatic adaptability in a particular region (Mahajan and Dhillon, 2000; Kumar et al., 2014), which might prove an important diagnostic character for the selection of the appropriate cultivar for local conditions (Kumari et al., 2015). The geometric attributes that promote fruit quality, such as the geometric mean diameter, surface area, sphericity index, aspect ratio, length, minor and major diameters, were related to the individual cultivars. \Furthermore, as explained by Obeed et al. (2008), changes in Indian jujube (*Ziziphus mauritiana* Lamk.) cultivars are linked with genetic diversity. Moreover, the geometric attributes of the Indian jujube fruit cultivar play -

a key role in determining Indian jujube fruit quality because jujube fruits may be graded according to shape, size, and color. Currently, a standard suitable grading system has not been utilized for Indian jujube fruits (Pareek and Yahia, 2013). The Indian jujube fruit is classified into three categories according to Pareek and Gupta (1988). The first category consists of grade fruit A, which has no blemishes and is of uniform size (large (>35 mm) to medium size (24–35 mm)) with a shining yellow color. The second category is grade B, which has some blemishes, a uniform fruit shape (large (>35 mm) to medium (25–35 mm)), and uneven yellow or yellow red color. The third category is grade C, in which the fruit is red and large (>35 mm) or small (<25 mm) with an uneven yellow color. Such geometric attributes can be used when fabricating the components of a specific machine. Furthermore, Razi et al. (2013) found that different morphological attributes such as fruit shape in Indian jujube cultivars showed substantial similarities and dissimilarities among different cultivars. Fruit shape varied from oblong to oval, ovate, and round in different cultivars. Moreover, the fruit diameter is of commercial importance for fruit marketing and trade/business (Kassem et al., 2011). Generally, the quality of fruits is considered to be impaired in excessively large or small fruits (Nawaz et al., 2008).

Skin color appearance, specifically fruit color, is a serious objective factor that can be used as a quality guide. The color of a fruit can be defined by many color coordinate systems, such as RGB (red, green, blue), Hunter Lab, C.I.E. (Commission Internationale de l'Eclairage), L*a*b*, CIE XYZ, C.I.E. Yxy, and CIE LCH (Urbonaviciene et al., 2012). The most commonly used color system in the food industry is the C.I.E. L*a*b* system (Giese, 2000). Fruit color is one of the most significant quality characteristic that affects fruit marketing. After harvesting, the increase in the chlorophyll breakdown, anthocyanin accumulation, and the acceleration of the carotenoid synthesis, depending on the increase of ethylene in the fruit, changes the color of the fruit (Öztürk and Ağlar, 2019).

5. Conclusions

From the above mentioned results, it is generally noticed that fruit properties of 11 Indian jujube cultivars differed extremely in their physical, mechanical, and chemical properties among the cultivars tested. The data obtained revealed a new information about Indian jujube with superior traits in a high quality product with economical interest. They are useful for designing and developing machines and equipment for harvesting and processing operations as well as, transportation, handling, packing, separating, sorting, processing, maintaining fruit quality for customers and the better marketability.

Declaration of Competing 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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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sjbs.2021.03.006.

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