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Research Article

Chitosan Coating Ameliorates Postharvest Quality and Extends the Shelf Life of Jujube (*Ziziphus mauritiana*) at Ambient Conditions

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ABSTRACT

The short shelf life of jujube is a problem for postharvest preservation and the fruit industry. This study aimed to evaluate the effect of chitosan on postharvest quality, including the shelf life of jujube. The experiment consisted of four treatments (control, 0.1% chitosan, 0.3% chitosan, and 0.5% chitosan) and five jujube varieties (Ball Sundori Kul, Apple Kul, Kashmiri Kul, Thai Kul, and Narkeli Kul) and was laid out in a Completely Randomized Design with three replications. Data were collected on weight loss, fruit length, breadth, color attributes [L* (lightness), a* (redness or greenness), b* (blueness or yellowness), C* (chroma), and h° (hue angle)], total soluble solids (TSS), titratable acidity, vitamin C, pH, flavonoids, anthocyanins, and disease incidence, generally at 3, 6, and 9 days after storage (DAS). Fruits were also evaluated for shelf life. The minimum weight loss (14.33%) was recorded from 0.5% chitosan-coated Ball Sundori Kul. The 5% chitosan also resulted in better colorimeter values (*L, a*, b*, C*, and h*) than the other treatments. Ball Sundori Kul coated with 0.5% chitosan showed the highest Vit C (19.62 mg100g^{-1}) and TSS (15.13%), while uncoated fruit had the highest pH (4.11) at 9 DAS. Moreover, Ball Sundori Kul coated with 0.5% chitosan retained the highest total flavonoid (0.90 mg100g^{-1}) and total anthocyanin (35.25 mg100g^{-1}), and the lowest disease incidence (55%). Furthermore, Ball Sundori Kul coated with 0.5% chitosan had the highest shelf life (9 days). Therefore, jujube fruits, particularly Ball Sundori Kul, can be coated with 0.5% chitosan for postharvest preservation.

Introduction

Jujube (*Ziziphus mauritiana*) is a tropical fruit with economic significance. It is a member of the Rhamnaceae family, and also known as Ber. It has a poor shelf life and is highly perishable (Meena et al., 2009). Customers are attracted to this fruit due to its mouthwatering flavor, appealing scent, and substantial nutrient content (Rashwan et al., 2020). It has a high calorific value, a high ascorbic acid content, and an adequate amount of calcium, phosphorus, iron, and vitamins A and B (Jawanda et al., 1978).

Fresh fruits decay quickly and cannot be stored at room temperature for longer than 10 days without experiencing severe degradation (Kadzere et al., 2004; Pareek, 2001). Numerous techniques, such as lowering the temperature, storing in a controlled atmosphere, applying preservatives, or coating edible film, were considered to preserve the physiological quality and extend the shelf life of fresh fruits (Nallathambi et al., 2009; Rao et al., 2016; Wu et al., 2010; Zhang et al., 2014). Chitosan has emerged as one of the most widely used edible film materials in recent years, replacing chemical fungicides. Chitosan is an organic polysaccharide, obtained through deacetylation of chitin, which is available in nature. it is a nontoxic and biocompatible biopolymer with exceptional film-forming qualities (El-Badawy and ElSally, 2011; Hong et al., 2012; Xing et al., 2011). It can create a semipermeable film on fruit that may alter the internal atmosphere, reduce weight loss and shriveling brought on by transpiration, and improve the overall quality of the fruit (Munira et al., 2024). By stopping the loss of fruit weight, soluble solid contents, vitamin C, titratable acidity, and firmness, chitosan coating preserves fruit quality while it is being stored (Chiabrando and Giacalone, 2013; Lin et al., 2020; Munira et al., 2024; Romanazzi et al., 2002).

Papaya fruit treated with chitosan showed slight changes in peel color, as seen by the slower rise in

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brightness and chroma values compared to uncoated fruits. The papaya fruit treated with 1.0%, 1.5%, and 2.0% chitosan may have delayed color development, fruit ripening, and senescence due to reduced ethylene production and a slowed respiration rate (Ali et al., 2011). The combination of chitosan and calcium also postponed changes in the surface color of papaya fruit, as evidenced by the lower brightness and chroma values and the higher hue angle value in treated papaya compared to untreated papaya (Al Eryani et al., 2008). Chitosan coating increased total soluble solids, decreased fruit weight loss, and delayed the drop in titratable acidity and ripening of papaya (Al Eryani et al., 2008). Moreover, chitosan treatment delayed changes in eating quality, respiration rate, and weight loss while increasing the total soluble solids and titratable acidity in longan (Jiang and Li, 2001) and guava (Hong et al., 2012). Chitosan also delayed the increase in total soluble solids during storage of mango fruit and considerably avoided the decline in respiration rate, fruit weight, and titratable acidity (Jitareerat et al., 2007). Mango fruit coated with chitosan and hydrothermally treated lost less weight, had a higher acidity, a lower pH, and soluble solids regardless of the hydrothermal process (Salvador-Figueroa et al., 2011). However, a few studies have been conducted regarding postharvest quality attributes of jujube in Bangladesh. Therefore, the present study evaluated the effects of chitosan on postharvest quality and shelf life of jujube fruits at ambient conditions.

Materials and methods

Experimental material and design

This experiment was conducted to determine the effect of chitosan coating on the physico-chemical quality of jujube fruit varieties from 18 December to 26 December 2022. Five jujube varieties—Ball Sundori Kul, Apple Kul, Kashmiri Kul, Thai Kul, and Narkeli Kul—were evaluated in this study. The jujube fruits were collected from the Satkhira district of Bangladesh and transferred to the lab with an air-cooled vehicle. The chitosan stock solution was made by weighing 5 g of synthesized chitosan with an electric balance and thoroughly mixing it with 250 ml of vinegar and 250 ml of distilled water to reach a volume of 500 ml. The solution was then diluted to 0.1%, 0.3%, and 0.5% with distilled water.

Fruits were cleaned with tap water to remove any dirt or dust, and fresh, fully mature, and disease-free jujube fruits were allowed to dry at room temperature. Ball Sundori Kul, Apple, Kashmiri Kul, Thai, and Narkeli Kul fruits were separated into four sections for the application of four different treatments: T1 = control, T2 = 0.1%, T3 = 0.3%, and T4 = 0.5% chitosan. The selected jujube fruits were allocated at random to the treatments. The chitosan solutions were sprayed to soak them entirely. Then, the fruits were stored at room temperature on a newspaper on the lab table. A completely randomized design (CRD) with three replications was used to set up the two-factor experiment, and each replication had 400 g of fruits. Fruits were evaluated for physicochemical attributes at three-day intervals.

Determination of weight loss

Weight loss of jujube fruit was calculated according to the following formula (Dhali et al., 2024; Kabir and Hossain, 2024).

$$\text{Weight loss (\%)} = \frac{Mo - Mi}{Mo} \times 100 \quad \text{.................... (1)}$$

Where, M_0 represents the fresh weight of fruit at day 1, and M_i indicates fruit the fresh weight at a particular day, where i is 1, 2, 3, the n^{th} day.

Fruit size determination

The length (cm) and breadth (cm) of fruit size were measured with a slide caliper.

Surface color determination

The Commission International de I'Eclairage (CIE) LAB color parameters were used to measure the surface color of two sides of jujube fruit on the equatorial zone using a chromameter (CR-400, Konica Minolta, Japan). Between 0 (black) and 100 (white), the chromaticity L* denotes how light the fruit color is; a* denotes how red (+a*) or green (-a*) the fruit skin is; and b* denotes how yellow (+b*) or blue (-b*) it is. In terms of color interpretation, the angles of red, yellow, green, and blue were 0°, 360°, 90°, and 180°, respectively. The hue angle (h°) and chroma (C*) were calculated according to the following formulae (McGuire, 1992).

$$\text{Hue angle (h°)} = \tan^{-1} b^*/a^* \quad \text{.. (2)}$$

$$\text{Chroma } (C^*) = (a^{*2} + b^{*2})^{1/2} \quad \text{.. (3)}$$

Where a* and b* are the measurements obtained from the chromameter. C* the strength of color saturation from dull to brilliant (low-to-high values, respectively.

Determination of vitamin C content

Vitamin C content of jujube is determined following dye titration method [Nerdy (2018); Lekhon et al. (2024)].

$$\text{Vitamin C } (\text{mg}100\text{g}^{-1}) = \frac{e \times d \times b}{c \times a} \quad \text{...... .... (4)}$$

In this case, a stands for sample weight, b for final volume (after adding metaphosphoric acid), c for aliquot volume, d for dye factor, and e for mean burette reading.

Determination of TSS and TA

To determine total soluble solids (TSS), one drop of extracted jujube fruit juice was put on the refractometer prism and the reading was recorded.

Titratable acidity (TA) was measured through the titration [Nerdy (2018); Dhali et al. (2024)] as

TA (%) = $100\times\frac{d\times 0.064\times c}{a\times b}$ .... (5)

Here, d is the mean burette reading, a is the sample weight, b is the aliquot volume, and c is the final volume created with distilled water. Since 1 ml of 0.1 N NaOH neutralizes 0.064 g of citric acid, the titration factor is 0.064.

pH Measurement

A desktop pH meter was used to measure the fruit's pH at room temperature (28±2˚C). In a beaker, 5 g of the sample was combined with 10 mL of distilled water to prepare juice. The pH of the sample was then determined by dipping the pH meter into the beaker.

Determination of Anthocyanin

Amount of anthocyanin was determined according to Lekhon et al. (2024).

Total Absorbance value of the sample (per 100g*)* =

$\frac{e\times b\times c}{d\times a}\times 100$ .... (6)

Where, a is the sample's weight and b is the volume of material used to measure color. c = Total volume made, d = Volume of estimated aliquot, and e = Volume for measuring absorbance at 535 nm.

Amthocyanin($mg100g^{-1}$) = Total absorbance ÷ 98.2.........(7)

Where, 98.2 is a constant.

Determination of total flavonoid

Ten g of finely crushed fruit pulp was combined with 100 ml of 80% methanol, incubated for 10 hours at 40 °C in a water bath, filtered, and the filtrate was evaporated to dry in a water bath at room temperature in order to determine the total flavonoid concentration. To calculate the total flavonoid, the remaining ones were weighed.

Fruit disease incidence

Disease incidence refers presence of visible disease in fruit. Visible signs and black spots were regarded as diseased fruit. Disease incidence is calculated according to Ullah (2007) as follows:

Disease incidence (%) = $\frac{Number\,of\,\inf ected\,fruit}{Total\,number\,of\,\,fruits}\times 100$..... (8)

Shelf Life

The number of days that the fruits stayed in good condition was recorded in order to calculate the shelf life. In this context, the number of days needed for disease incidence and the number of days needed to record at least 20% of fruits as diseased were taken into account. To determine shelf life, the number of days needed to achieve a 20% weight drop was also taken into account (Tabassum et al., 2018).

Statistical analysis

The statistical program Statistix-10 (Analytical Software, 2105 Miller Landing Rd, Tallahassee, FL 32312) was used to do a two-way analysis of variance (ANOVA) on the data, and the means were separated at the 5% level of probability using Duncan's Multiple Range Test (DMRT).

Results

Physical attributes of jujube fruit

Weight loss of fruits

The physiological loss in weight of the fruit increased significantly during the storage period (Table 1). The uncoated Narkeli Kul lost maximum physiological weight (32.91%), followed by the uncoated Thai Kul (30.83%). On the other hand, the treatment with 0.5% chitosan coating displayed superior results, with minimum weight loss in Ball Sundori Kul (14.33%), followed by the Kashmiri Kul treated with 0.3% chitosan (15.75%) and the Kashmiri Kul treated with 0.5% chitosan (16.67%).

Size (length and breadth)

There were significant interaction effects of jujube varieties and chitosan coating regarding length and breadth (Table 2) of fruits. Ball Sundori Kul resulted in the largest fruit (52.57 cm) if coated with 0.5% chitosan solution, and uncoated Thai Kul was the smallest (30.29 cm), followed by uncoated Apple Kul (31.70 cm) and Apple Kul (31.74 cm) with 0.3% chitosan coating (Table 2). Similarly, Ball Sundori Kul was the widest cultivar (40.99 cm) if coated with 0.5% chitosan, followed by the Kashmiri Kul coated with 0.5% chitosan (40.29 cm), and the Ball Sundori Kul coated with 0.3% chitosan (40.11 cm). The uncoated Thai Kul was the narrowest one (25.14 cm), which was statistically similar to the uncoated Apple Kul (26.73 cm) and the uncoated Kashmiri Kul (26.21 cm) (Table 2).

Table 1. The interaction effect of variety and chitosan coating on weight loss of jujube fruit at different days after storage (DAS).

Treatments	Weight loss (%) [a]		
	3DAS	6DAS	9DAS
V_1T_1	11.75bcd	15.41efg	19.0hij
V_1T_2	11.50bcde	14.33efg	16.83ijk
V_1T_3	8 .0ef	12.29ghh	15.75jk
V_1T_4	7.41f	9.58h	14.33k
V_2T_1	12.41bc	17.29def	23.33efg
V_2T_2	14.58b	21.0cd	27.50bcd
V_2T_3	10.41cdef	17.08def	20.41ghi
V_2T_4	8.58def	13.20fgh	21.16fgh
V_3T_1	14.25b	21.08cd	24.58def
V_3T_2	12.16bcd	18.12de	22.91efgh
V_3T_3	9.91cdef	15.87efg	20.41ghi
V_3T_4	8.58def	12.20gh	16.67ijk
V_4T_1	21.0a	28.41a	30.83ab
V_4T_2	12.41bc	18.37de	23.75defg
V_4T_3	22.5a	26.08ab	29.18abc
V_4T_4	20.41a	22.83bc	26.75cde
V_5T_1	23.0a	27.91a	32.91a
V_5T_2	12.0bcd	17.54de	23.33efg
V_5T_3	12.23bc	18.16de	26.33cde
V_5T_4	20.83a	24.87abc	29.16abc
Significance	**	**	**
CV (%)	15.97	13.94	10.30

[a] V_1 = Ball Sundori Kul, V_2 = Apple Kul, V_3 = Kashmiri Kul, V_4 = Thai Kul, V_5 = Narkeli Kul, T_1 = Control, T_2 = 0.1% chitosan, T_3 = 0.3% chitosan, and T_4 = 0.5% chitosan. In a column, different letter (s) indicate significant differences among the treatments at 5%. ** means significant at 1%. CV = Coefficient of variation.

Table 2. The interaction effect of variety and chitosan coating on the length and breadth of jujube fruit on different days after storage (DAS).

Treatments [a]	Length (cm)			Breadth (cm)		
	3DAS	6DAS	9DAS	3DAS	6DAS	9DAS
V_1T_1	39.15ef	38.82ef	37.26f	33.33e	31.78g	30.40hi
V_1T_2	41.60bcdef	40.74cdef	38.89def	36.93bcd	34.26efg	32.53fgh
V_1T_3	55.32a	53.60a	51.78ab	41.93bc	41.51a	40.11a
V_1T_4	55.74a	53.73a	52.57a	42.11a	41.53a	40.99a
V_2T_1	34.41gh	33.66hi	31.70gh	28.89f	27.84i	26.73j
V_2T_2	35.67g	35.44gh	37.95g	29.37f	29.02hi	27.60ij
V_2T_3	34.39gh	33.60hi	31.74g	39.03ab	38.41bc	37.26bc
V_2T_4	53.00a	51.13a	49.10b	39.88ab	39.70ab	38.63ab
V_3T_1	43.38bcd	42.25bcd	40.61cde	28.55f	27.60i	26.21j
V_3T_2	43.42bc	42.72bc	41.60cd	39.06ab	38.34bcd	36.92bcd
V_3T_3	42.04bcde	41.02cde	39.48cdef	38.22b	36.93cde	35.66cde
V_3T_4	54.29a	52.40a	50.79ab	41.96a	41.30a	40.29a
V_4T_1	32.40h	31.74i	30.29gh	27.02f	26.28i	25.14j
V_4T_2	41.39cdef	40.17cdef	38.73ef	34.64cde	33.35fg	31.75fgh
V_4T_3	41.73bcdef	40.57cdef	39.43cdef	33.22e	31.54gh	30.52h
V_4T_4	44.61b	44.09b	41.95c	33.55e	31.92g	30.91gh
V_5T_1	38.81f	38.00fg	36.72f	37.97bc	35.65def	34.19def
V_5T_2	40.79cdef	39.47def	37.49f	34.45de	34.71ef	33.53efg
V_5T_3	40.39def	40.48cdef	38.44ef	37.07bcd	34.19efg	33.00efgh
V_5T_4	32.02bcde	40.48cdef	38.82def	37.32bcd	35.83cdef	34.50cdef
Significance	**	**	**	**	**	**
CV (%)	4.28	4.16	4.33	5.66	4.80	5.14

[a] V_1 = Ball Sundori Kul, V_2 = Apple Kul, V_3 = Kashmiri Kul, V_4 = Thai Kul, V_5 = Narkeli Kul, T_1 = Control, T_2 = 0.1% chitosan, T_3 = 0.3% chitosan, and T_4 = 0.5% chitosan. In a column, different letter (s) indicate significant differences among the treatments at 5%. ** means significant at 1%. CV = Coefficient of variation.

Fruit color change

Treatments with chitosan affected the chromaticity color coordinates, such as L* in jujube (Table 3). From the beginning to the end of the storage life, the L-value showed a progressive increase in lightness. The Ball Sundori Kul treated with 0.5% chitosan recorded the highest L* value (53.22), indicating whiter fruits, and the uncoated Thai Kul had the lowest value (36.18) (Table 3). Greenness is indicated by a negative a* value, while redness is a positive a* value. Fruit loses its greenness when the negative value gradually drops while being stored. Regardless of treatment, the negative a* value dropped from the harvest date to the end of their storage life. The color attributes a* was noteworthy; at 9 DAS, the Thai Kul coated with 0.3% chitosan recorded the highest value of a* (-1.47), i.e., fruits turn almost red, while the uncoated Apple Kul had the lowest value (-6.0) (Table 3).

Table 3. The interaction effect of variety and chitosan coating on the Color L* and Color a* of jujube fruit on different days after storage (DAS).

Treatment [a]	Color L*			Color a*		
	3DAS	6DAS	9DAS	3DAS	6DAS	9DAS
V_1T_1	27.93cd	38.34cd	40.27ghi	-5.8i	-4.3bcd	-4.2defg
V_1T_2	30.38c	38.44cd	45.09cdef	-5.5hi	-5.1defg	-5.3efg
V_1T_3	36.34b	49.73a	49.37ab	-4.5c-i	-4.8cdef	-5.6fg
V_1T_4	42.62a	51.69a	53.22a	-5.3ghi	-3.3b	-3.5bcde
V_2T_1	36.98b	38.28cd	44.71cdef	-1.8a	-4.2bcd	-6.0g
V_2T_2	27.99cd	43.85bc	44.33defg	-3.7b-f	-5.0defg	-3.5bcde
V_2T_3	21.52g	31.19ef	40.38gh	-3.32bcd	-1.7a	-3.7bcde
V_2T_4	21.64g	31.95e	48.36bcd	-3.3bc	-5.9gh	-3.3bcd
V_3T_1	22.28fg	40.50c	44.43cdefg	-5.8i	-5.6fgh	-2.5abcd
V_3T_2	25.33def	47.31ab	46.63bcde	-4.7d-i	-3.6b	-2.0ab
V_3T_3	23.48efg	47.71ab	42.68efg	-3.2bc	-3.6b	-2.4abcd
V_3T_4	20.54g	47.81ab	48.58bc	-2.6ab	-6.3h	-3.5bcde
V_4T_1	20.08g	22.52g	36.18i	-4.8fghi	-4.9defg	-3.9cdef
V_4T_2	27.24cd	40.82c	41.25fg	-3.2bc	-4.2bcde	-5.2efg
V_4T_3	26.45de	42.35bc	42.02fg	-3.5bcde	-3.8bc	-1.4a
V_4T_4	25.98de	47.37ab	36.59hi	-2.6ab	-5.2efgh	-2.6abcd
V_5T_1	21.05g	25.52fg	43.75efg	-4.9fghi	-5.0defg	-3.0abcd
V_5T_2	28.17cd	34.05de	44.32defg	-4.3c-h	-4.2bcd	-2.6abcd
V_5T_3	27.83cd	30.03ef	44.37defg	-4.0c-g	-5.2defg	-3.1abcd
V_5T_4	30.58c	34.34de	44.81cdef	-4.1c-g	-4.3bcde	-2.2abc
Significance	**	**	*	*	**	*
CV (%)	8.93	5.71	6.42	-19.95	-14.70	-32.04

[a] V_1 = Ball Sundori Kul, V_2 = Apple Kul, V_3 = Kashmiri Kul, V_4 = Thai Kul, V_5 = Narkeli Kul, T_1 = Control, T_2 = 0.1% chitosan, T_3 = 0.3% chitosan, and T_4 = 0.5% chitosan. In a column, different letter (s) indicate significant differences among the treatments at 5%. * and ** mean significant at 5% and 1%, respectively. CV = Coefficient of variation. Chromaticity L* indicates the lightness of the fruit color, ranging from 0 (black) to 100 (white), and a* represents the redness (+a*) or greenness(−a*).

Yellowness is determined a positive b* value, which increases from the day of harvest until the end of their storage life. The Ball Sundori Kul treated with 0.3% chitosan recorded the highest b* value (18.41), i.e., more yellow at 9DAS, whereas the uncoated Narkeli Kul had the lowest b* value (10.49), i.e., less yellow (Table 4). Ball Sundori Kul coated with 0.3% chitosan had the highest estimated C* value at 9 DAS (17.17), indicating higher color saturation, while uncoated Narkeli Kul had the lowest (6.43), i.e., lower color saturation (Table 4). The uncoated Thai Kul obtained the lowest hue angle (96.39), suggesting fruits were yellow, while 0.1% chitosan-coated Ball Sundori Kul resulted in the highest hue angle (127.98), i.e., fruits were more yellow at 9 DAS (Table 5).

Table 4. The interaction effect of variety and chitosan coating on the Color b* and C* value of jujube fruit on different days after storage (DAS).

Treatments [a]	Color b*			Color C*		
	3DAS	6DAS	9DAS	3DAS	6DAS	9DAS
V_1T_1	5.99gh	14.16de	12.72ghi	13.99fgh	14.78def	7.33ij
V_1T_2	6.83fgh	12.83efg	12.97fghi	14.10fgh	13.82defg	8.67ghi
V_1T_3	16.22a	19.92a	18.41a	18.99a	20.50a	17.17a
V_1T_4	16.11a	19.74a	17.67ab	18.47ab	20.03ab	16.49a
V_2T_1	5.51h	11.24fgh	15.03cde	15.49cdef	12.36ghi	6.53j
V_2T_2	9.49cd	12.92efg	15.74bcde	15.85cdef	12.94fghi	11.27cd
V_2T_3	10.76c	6.56jk	15.21cd	15.59cdef	6.79k	11.36c
V_2T_4	12.55b	17.15bc	14.80cdef	15.17defg	18.19bc	13.00b
V_3T_1	6.86fgh	14.51de	14.3efgh	15.43defg	15.56de	7.31ij
V_3T_2	8.38def	14.55de	16.96abc	17.59abc	15.00def	8.64ghi
V_3T_3	7.56efg	15.56cd	12.89fghi	13.29ghi	15.98cd	7.95hij
V_3T_4	15.29a	18.19ab	16.87abcd	17.08abcd	19.29ab	15.70a
V_4T_1	6.28gh	13.36def	11.49ij	12.54hi	14.32defg	7.41ij
V_4T_2	9.57cd	12.78efg	14.23efgh	14.59efgh	13.47efgh	10.93cde
V_4T_3	9.3cd	12.59efg	12.22hij	12.73hi	13.20fghi	10.29cdef
V_4T_4	9.24cd	12.18efgh	16.62abcd	16.83bcd	13.29efgh	9.62efg
V_5T_1	5.67h	5.26k	10.49j	11.61i	7.28k	6.43j
V_5T_2	8.87de	10.12hi	14.70defg	15.37defg	10.995ij	9.24fgh
V_5T_3	6.56gh	8.49ij	16.11bcde	16.62bcde	9.99j	7.33ij
V_5T_4	9.45cd	10.85ghi	16.59abcd	17.12abcd	11.72hij	9.73defg
Significance	**	**	**	**	**	**
CV (%)	10.45	10.98	8.93	8.44	9.85	9.29

[a] V_1 = Ball Sundori Kul, V_2 = Apple Kul, V_3 = Kashmiri Kul, V_4 = Thai Kul, V_5 = Narkeli Kul, T_1 = Control, T_2 = 0.1% chitosan, T_3 = 0.3% chitosan, and T_4 = 0.5% chitosan. Chromaticity b* indicates the yellow (+b*) or blue (−b*), and chroma (C*) is the intensity of color saturation from dull to vivid color (low-to-high values, respectively). In a column, different letter (s) indicate significant differences among the treatments at 5%. ** means significant at 1%. CV = Coefficient of variation

Table 5. The interaction effect of variety and chitosan coating on the hue angle (h°) of jujube fruit on different days after storage (DAS).

Treatments	Hue angle (h°) [a]		
	3DAS	6DAS	9DAS
V_1T_1	114.65a	106.64cde	125.26ab
V_1T_2	113.09ab	111.85cd	127.98a
V_1T_3	103.96bcd	103.53ef	109.14abc
V_1T_4	106.63abc	99.79fg	102.39cd
V_2T_1	103.92bcd	114.46bc	122.10ab
V_2T_2	96.74d	93.50g	122.83abc
V_2T_3	102.34cd	104.59cde	108.80abc
V_2T_4	102.62cd	109.52cde	105.17bcd
V_3T_1	111.90abc	111.21cd	110.22abc
V_3T_2	105.39abc	104.01def	103.96bcd
V_3T_3	104.13bcd	103.16efg	107.88abc
V_3T_4	99.05d	109.41cde	103.06cd
V_4T_1	113.29ab	110.47cd	96.39d
V_4T_2	102.76cd	108.54cde	118.94ab
V_4T_3	105.89abc	107.26cde	122.10ab
V_4T_4	99.05d	113.68bcd	106.05bcd
V_5T_1	115.01a	133.53a	118.07abc
V_5T_2	106.40abc	112.78bc	106.22abc
V_5T_3	104.29bcd	121.77b	116.39abc
V_5T_4	104.07bcd	111.90bcd	103.96bcd
Significance	**	**	**
CV (%)	3.03	2.91	6.28

[a] V_1 = Ball Sundori Kul, V_2 = Apple Kul, V_3 = Kashmiri Kul, V_4 = Thai Kul, V_5 = Narkeli Kul, T_1 = Control, T_2 = 0.1% chitosan, T_3 = 0.3% chitosan, and T_4 = 0.5% chitosan. The values of the hue angle (h°) denote absorbance or reflection relate to intrinsic brightness. For color interpretation, red was at an angle of 0° or 360°, yellow at 90°, green at 180°, and blue at 270°. In a column, different letter (s) indicate significant differences among the treatments at 5%. ** means significant at 1%. CV = Coefficient of variation.

Chemical properties of jujube fruits

TSS and TA

The TSS of the fruit increased significantly during the storage period (Table 6). At 9 DAS, Ball Sundori Kul coated with 0.3% chitosan recorded the highest TSS (15.13%), which was statistically similar to Apple Kul coated with 0.5% chitosan (14.87%). The uncoated Narkeli Kul had the lowest TSS (10.40%), followed by the uncoated Apple Kul (10.97%) and the Apple Kul coated with 0.3% chitosan (11.00%) (Table 6). The untreated Thai Kul had the highest TA (4.00%) at 9DAS, followed by Kashmiri Kul treated with 0.5% chitosan (3.57%), and Apple Kul treated with 0.1% chitosan (3.53%). However, 0.5% chitosan-coated Ball Sundori Kul had the lowest TA (1.40%), followed by Thai Kul treated with 0.1% chitosan (1.60%) and Ball Sundori Kul treated with 0.5% chitosan (1.40%) (Table 6).

Table 6. The interaction effect of variety and chitosan coating on total soluble solids (TSS) and Titratable acidity (TA) of jujube fruit on different days after storage (DAS).

Treatments [a]	TSS (%)			TA (%)		
	3DAS	6DAS	9DAS	3DAS	6DAS	9DAS
V_1T_1	10.50defg	11.35cdef	11.97h	5.93b	3.28de	2.26ef
V_1T_2	10.87cdef	11.88bcd	13.60cd	4.27d	3.93bc	2.87cd
V_1T_3	12.50a	13.23a	15.13a	6.93a	4.75a	3.41b
V_1T_4	12.97a	12.88ab	14.40b	0.90f	4.78a	1.40h
V_2T_1	9.93fg	10.17def	10.97j	1.00g	2.02h	2.07efg
V_2T_2	10.20defg	10.15f	11.16f	5.00cd	3.90bc	3.53ab
V_2T_3	10.90cdef	11.88bcd	11.00i	5.63bc	2.88efg	2.37de
V_2T_4	12.00abc	12.78ab	14.30bc	3.20e	2.93ef	2.27ef
V_3T_1	10.03efg	11.73bcd	13.23de	2.90e	3.42cde	3.09bc
V_3T_2	9.90fg	11.25cdef	12.33gh	1.17f	2.17h	2.50de
V_3T_3	11.17bcde	11.98abcd	14.33b	5.67bc	3.70cd	3.20bc
V_3T_4	12.30ab	12.80ab	14.87ab	5.73bc	4.30ab	3.57ab
V_4T_1	10.10defg	11.87bcd	13.37d	0.90f	1.10j	4.00a
V_4T_2	10.07efg	11.67bcde	12.50fgh	0.97f	1.11j	1.60gh
V_4T_3	10.13defg	10.90def	11.00i	4.70d	1.93hi	2.83cd
V_4T_4	11.23bcd	12.27abc	13.00defg	4.43d	1.30j	1.80fgh
V_5T_1	9.53g	10.27ef	10.40j	1.20g	2.47fgh	3.17bc
V_5T_2	10.03efg	11.68bcde	12.57efgh	1.00f	2.38gh	2.43de
V_5T_3	11.03cdef	12.15abcd	13.10def	2.80e	2.72fg	2.17ef
V_5T_4	10.57defg	11.42cdef	12.30gh	4.40d	1.42ij	2.40de
Significance	*	**	**	**	**	**
CV (%)	6.42	6.66	3.42	13.40	11.58	11.82

[a] V_1 = Ball Sundori Kul, V_2 = Apple Kul, V_3 = Kashmiri Kul, V_4 = Thai Kul, V_5 = Narkeli Kul, T_1 = Control, T_2 = 0.1% chitosan, T_3 = 0.3% chitosan, and T_4 = 0.5% chitosan. In a column, different letter (s) indicate significant differences among the treatments at 5%. * and ** mean significant at 5% and 1%, respectively. CV = Coefficient of variation.

Vitamin C

At 9 DAS, Ball Sundori Kul treated with 0.5% chitosan obtained the maximum vitamin C (19.62 mg100g^{-1}), followed by Ball Sundori Kul treated with 0.3% chitosan (15.8 mg100g^{-1}) and Ball Sundori Kul treated with 0.1% chitosan (12.5 mg100g^{-1}). However, uncoated Narkeli Kul had the lowest vitamin C content (5.85 mg100g^{-1}), which was statistically similar to Ball Sundori Kul treated with 0.1% chitosan (6.9 mg100g^{-1}), Kashmiri Kul treated with 0.1% chitosan (9.4 mg100g^{-1}), and Narkeli Kul treated with 0.3% chitosan (9.6 mg100g^{-1}) (Table 7).

Fruit pH

The uncoated Ball Sundori Kul recorded the highest pH (4.11), which was statistically comparable to the uncoated Thai Kul (4.10), and the lowest pH (3.31) was found in Apple Kul coated with 0.3% chitosan, followed by Ball Sundori Kul coated with 0.1% chitosan (3.33) and Ball Sundori Kul coated with 0.5% chitosan at 9 DAS (Table 7).

Total Flavonoids

The total flavonoid of jujube fruits decreased significantly during the storage period (Table 8). The highest total flavonoid value (0.90 mg100g^{-1}) was recorded in Ball Sundori Kul coated with 0.5% chitosan. This was followed by Ball Sundori Kul coated with 0.3% chitosan (0.86 mg100g^{-1}), and Apple Kul coated with 0.5% chitosan (0.82 mg100g^{-1}). The lowest total flavonoid (0.41 mg100g^{-1}) was found in uncoated Thai Kul, preceded by 0.1% chitosan-coated Ball Sundori Kul (0.42 mg100g^{-1}) and untreated Narkeli Kul (0.49 mg100g^{-1}) (Table 8).

Table 7. The interaction effect of variety and chitosan coating on vitamin C and pH of jujube fruit on different days after storage (DAS).

Treatments [a]	Vitamin C (mg/100 g)			pH		
	3DAS	6DAS	9DAS	3DAS	6DAS	9DAS
V_1T_1	8.15ef	12.8bc	12.5c	3.22bc	3.35abc	4.11a
V_1T_2	5.95ghi	5.85h	6.9fg	3.10jk	3.27i	3.33fg
V_1T_3	16.25b	13.92b	15.8b	3.73d	3.65efgh	3.68cde
V_1T_4	23.7a	20.95a	19.62a	3.92ijk	4.13hi	3.41efg
V_2T_1	9.7de	9.68fg	11.1cd	3.09k	3.84cdef	3.99ab
V_2T_2	12.1c	9.62fg	11.55c	3.24i	3.38hi	3.54defg
V_2T_3	13c	12.28bcd	11.3cd	3.23ij	3.42ghi	3.31g
V_2T_4	9.8de	9.52fg	11.33cd	3.34hi	3.61efgh	3.96abc
V_3T_1	5.25hi	5.9h	7.8ef	3.41c	3.70ab	3.90abc
V_3T_2	7.8efg	10.05efg	9.4de	3.48fg	3.79def	3.69cde
V_3T_3	11.5cd	12.42bcd	12.4c	3.58ef	3.84cdef	3.79bcd
V_3T_4	12.15c	10.88def	12c	3.91gh	4.18defg	3.60defg
V_4T_1	4.95i	5.62h	6.75fg	4.07a	4.32a	4.10a
V_4T_2	11.6cd	13.55b	11.95c	3.74d	3.97bcd	3.84abcd
V_4T_3	5.75ghi	10.62defg	14.5b	3.63de	3.91bcde	3.77bcd
V_4T_4	7.3fgh	8.95g	11.05cd	4.05ab	4.01abcd	3.97abc
V_5T_1	5.7ghi	5.98h	5.85g	3.45gh	3.83cdef	3.56defg
V_5T_2	11.45cd	11.6cde	10.65cd	3.68de	3.91bcde	3.83abcd
V_5T_3	9.9de	10.58defg	9.6de	3.33hi	3.60efgh	3.65de
V_5T_4	6.9fghi	11.1cdef	10.93cd	3.21ijk	3.54fghi	3.62def
Significance	**	**	**	***	*	***
CV (%)	12.98	10.93	10.56	2.31	5.09	4.90

[a] V_1 = Ball Sundori Kul, V_2 = Apple Kul, V_3 = Kashmiri Kul, V_4 = Thai Kul, V_5 = Narkeli Kul, T_1 = Control, T_2 = 0.1% chitosan, T_3 = 0.3% chitosan, and T_4 = 0.5% chitosan. In a column, different letter (s) indicate significant differences among the treatments at 5%. *, ** and *** mean significant at 5%, 1%, and 0.1%, respectively. CV = Coefficient of variation

Anthocyanin of fruits

The highest concentration of anthocyanin (37.37 $mg100g^{-1}$) was recorded in the Ball Sundori Kul treated with 0.5% chitosan which was statistically similar to (35.74 $mg100g^{-1}$) Kashmiri Kul coated with 0.5% chitosan and the lowest concentration of anthocyanin (3.72 $mg100g^{-1}$) was found in Thai Kul coated with 0.1% chitosan preceded by uncoated Narkeli Kul (4.86 $mg100g^{-1}$) and uncoated Apple Kul (9.25 $mg100g^{-1}$) (Table 8).

Table 8. The interaction effect of variety and chitosan coating on total flavonoid and anthocyanin of jujube fruit at different days after storage (DAS).

Treatments [a]	Flavonoid (mg/100g FW)		Anthocyanin (mg/100g)	
	3DAS	9DAS	3DAS	9DAS
V_1T_1	0.75bcd	0.54defg	18.06de	17.83def
V_1T_2	0.63defg	0.42fg	24.13bc	22.65cd
V_1T_3	0.86ab	0.68bc	35.67c	32.52ab
V_1T_4	0.90a	0.83a	37.37a	35.25a
V_2T_1	0.78ab	0.75ab	6.83fg	9.25ghij
V_2T_2	0.69cdef	0.64cd	14.86e	13.86fghi
V_2T_3	0.74bcde	0.70bc	24.33bc	22.62cd
V_2T_4	0.82ab	0.78ab	27.85b	26.44ab
V_3T_1	0.61efg	0.55def	17.41e	15.91ef
V_3T_2	0.57fgh	0.52defg	22.50cd	21.79def
V_3T_3	0.54gh	0.60cde	27.95b	26.19abc
V_3T_4	0.80abc	0.72abc	35.74a	33.86ab
V_4T_1	0.46h	0.41g	4.79fg	19.01de
V_4T_2	0.73bcde	0.69bc	3.93g	3.72j
V_4T_3	0.68cdef	0.63cd	9.05f	8.92hi
V_4T_4	0.79abc	0.73abc	16.39e	16.21ef
V_5T_1	0.55gh	0.49efg	5.08fg	4.86ij
V_5T_2	0.57fgh	0.52defg	18.27de	17.56de
V_5T_3	0.57fgh	0.51defg	26.83bc	24.68bcd
V_5T_4	0.54gh	0.46fg	27.18bc	25.32abc
Significance	**	**	**	*
CV (%)	11.58	13.29	13.57	30.27

[a] V_1 = Ball Sundori Kul, V_2 = Apple Kul, V_3 = Kashmiri Kul, V_4 = Thai Kul, V_5 = Narkeli Kul, T_1 = Control, T_2 = 0.1% chitosan, T_3 = 0.3% chitosan, and T_4 = 0.5% chitosan. In a column, different letter (s) indicate significant differences among the treatments at 5%. * and ** mean significant at 5% and 1%, respectively. CV = Coefficient of variation.

Microbiological characteristics of jujube fruit

Disease incidence

The uncoated Narkeli Kul and Thai Kul got the highest disease incidence (83.33%), followed by 0.1% chitosan-coated Thai Kul (71.67%) and 0.5% chitosan-coated Thai Kul (70.60%). Ball Sundori Kul coated with 0.5% chitosan had the lowest disease incidence (55.00%), followed by Kashmiri Kul (58.33%) with 0.5% chitosan and Ball Sundori Kul (58.33%) with 0.3% chitosan (Table 9).

Table 9. The interaction effect of variety and chitosan coating on disease incidence of jujube fruit on different days after storage (DAS).

Treatments	Disease incidence (%) [a]		
	3DAS	6DAS	9DAS
V_1T_1	0.00b	36.67bcde	68.33abcd
V_1T_2	0.00b	38.33abcd	66.67abcd
V_1T_3	0.00b	25.00ef	58.33ef
V_1T_4	0.00b	23.33f	55.00f
V_2T_1	0.00b	30.00def	68.33abcd
V_2T_2	6.67ab	36.67bcde	65.00bcde
V_2T_3	0.00b	43.33abc	70.00abc
V_2T_4	0.00b	28.33def	61.67def
V_3T_1	6.67ab	25.00ef	63.33cde
V_3T_2	0.00b	30.00def	63.33cde
V_3T_3	6.67ab	23.33f	63.33cde
V_3T_4	0.00b	25.00ef	58.33ef
V_4T_1	6.67ab	46.67ab	83.33a
V_4T_2	6.67ab	43.33abc	71.67ab
V_4T_3	6.67ab	28.33def	63.33cde
V_4T_4	6.60ab	40.00abcd	70.60ab
V_5T_1	13.33a	50.00a	83.33a
V_5T_2	6.67ab	38.33abcd	65.00bcde
V_5T_3	0.00b	31.67cdef	63.33cde
V_5T_4	0.00b	40.00abcd	66.67abcd
Significance	NS	**	*
CV (%)	212.50	22.06	6.31

[a] V_1 = Ball Sundori Kul, V_2 = Apple Kul, V_3 = Kashmiri Kul, V_4 = Thai Kul, V_5 = Narkeli Kul, T_1 = Control, T_2 = 0.1% chitosan, T_3 = 0.3% chitosan, and T_4 = 0.5% chitosan. In a column, different letter (s) indicate significant differences among the treatments at 5%. * and ** mean significant at 5% and 1%, respectively. NS = nonsignificant, CV = Coefficient of variation.

Shelf life

The shelf life of jujube was significantly affected by the different postharvest treatments of chitosan concentration (Fig. 1). The maximum shelf life (9 days) was recorded in Ball Sundori Kul coated with 0.5% chitosan, whereas the minimum shelf life was recorded in uncoated Narkeli Kul (4 days).

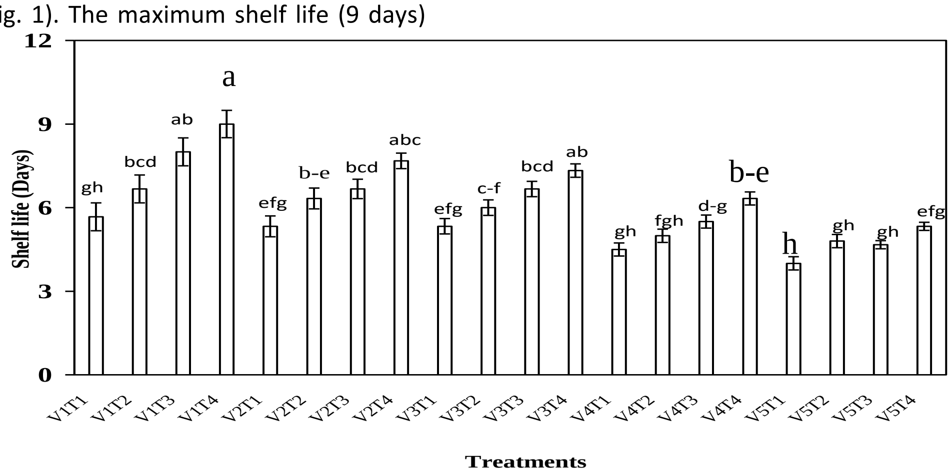

Fig. 1. The interaction effect of chitosan coating on the shelf life of jujube fruit. The bar represents mean ± standard error (SE). V_1 = Ball Sundori Kul, V_2 = Apple Kul, V_3 = Kashmiri Kul, V_4 = Thai Kul, V_5 = Narkeli Kul, T_1 = Control, T_2 = 0.1% chitosan, T_3 = 0.3% chitosan, and T_4 = 0.5% chitosan. On a bar, different letter (s) indicate significant differences among the treatments at 5%.

Discussion

The results showed that 0.5% chitosan-coated Ball Sundori Kul causes minimum fruit weight loss and keeps the fruit firmer than other treatments. Chitosan coatings act as a semi-permeable barrier against the flow of oxygen, carbon dioxide, moisture, and solutes, contributing to the decrease in weight loss by lowering respiration, water loss, and oxidation reaction rates (Baldwin et al., 1999). Chitosan coating minimizes the weight loss of apples by reducing the respiration rate (Shao et al., 2012). Similarly, chitosan coating delays water loss in cherries (Dang et al., 2010).

The Ball Sundori Kul was the largest fruit in length and breadth, and the effect of 0.5% chitosan was the best among the treatments. It may be due to the coating's anti-senescent properties inhibiting ethylene biosynthesis and delaying the activity of ripening enzymes and senescence, preventing cell degradation and decreasing shrinkage (Sudha et al., 2007). According to Shokrollahfam et al. (2012), increased enzyme activity that broke down the cell wall structure caused tissue metabolism to rise and tissue and cellular strength to fall, which was the main contributor to shrinking the diameter of fruit during storage. Metabolic activity, transpiration, and respiration tend to soften or reduce the firmness of fruit tissue, which decreases during storage (Fischer, 1991; Prasana et al., 2007). Similarly, grapevine and mango fruits treated with chitosan showed noticeably longer fruits (Alwea, 2018; Ibrahim et al., 2019).

Throughout storage, chitosan treatments typically increased L*, a*, and b* and decreased C* and h°, suggesting that chitosan may postpone the jujube fruit's color development process. Chitosan coating delayed the decrease in L* of bananas and strawberries (Petriccione et al., 2015; Purwoko et al., 2002). Similar to this study, Ngo et al. (2021) reported a higher negative value of a* in fruits coated with nano-chitosan. According to the present study, fruits covered with chitosan also maintained their maximal color b*. The C* value of the fruit dropped, and the color angle rose in strawberries kept in cold storage, suggesting the consequence of variations in the fruits or storage conditions (Koyuncu, 2004). The synthesis and breakdown of carotenoids and phenolic pigments like anthocyanins, as well as the breakdown of chlorophyll, can all contribute to changes in fruit color (Lancaster et al., 1997).

Vitamin C content generally decreased during storage. However, vitamin C content was higher in chitosan-treated fruits than in untreated ones. By blocking oxygen from reaching the fruits, the coating has the benefit of reducing ascorbic acid oxidation (Oluwaseun, 2013). Similarly, jujube fruits coated with chitosan and treated with $CaCl_2$ had greater ascorbic acid levels, and chitosan can retain ascorbic acid content for a longer period since it postpones ripening (Park, 1999).

The uncoated jujube fruits have lower TSS than the chitosan-coated fruits. The increase in TSS contents is known to be due to the hydrolytic change in starch, and the conversion of starch to sugar is an index of the ripening process in fruits (Arthy and Philip, 2005), and also a decrease in respiration rate and conversion of sugar to carbon dioxide and H_2O at a later stage of storage. TA decreases as the chitosan concentration increases compared to uncoated fruits. Reducing titratable acidity is caused by the Krebs cycle, which oxidizes organic acids throughout the ripening process to create energy reserves for fruits (Kays, 1991). Similarly, TA levels of sapodilla fruit decreased with the application of chitosan coatings (Bahmani et al., 2015).

The change in pH is due to the treatment's effect on the fruit's biochemical condition and a slower rate of respiration and metabolic activity. The breakdown of acids during storage through respiration could be the cause of the pH rise (Abbasi et al., 2009). The increase in pH may be due to the continuous reduction of acidity during ripening. In the current study, a rise in pH was noted throughout the storage period. This outcome is consistent with the study by Pathak and Sanwal (1999), who found that soaking banana fruits in a 0.2% chitosan solution caused the pH of the fruit pulp to rise more quickly. The results of this study were similarly consistent with those of Kumar and Singh (1993), who noted that the pH of mango pulp rose while it was being stored.

The loss of total flavonoids in fruits may be caused by a greater respiration rate (Gil et al., 1998). Chitosan edible-coated fruits have a film layer that can control the temperature surrounding the fruit's surface, preventing respiration and slowing down the rapid breakdown of all the flavonoids (Riva et al., 2020; Fawole et al., 2020). Anthocyanin content of jujube rises during the start of the fruit's color development and falls as it ripens and reaches maturity (Bastos et al., 2016). Shi et al. (2018) also observed that when the ripening stage advances, the anthocyanin content falls.

Chitosan coating decreased postharvest disease incidence in jujube fruits. Applying 0.5% and 1% chitosan coating reduced the incidence of brown rot in peaches (Li and Yu, 2001). Applying 1% chitosan coating also reduced the incidence of postharvest diseases in sweet cherries (Feliziani et al., 2013).

Chitosan treatment increased the jujube’s shelf life. The 0.5% chitosan coating was better suited for increasing the shelf life of jujube than other treatments. Chitosan coating and garlic extract increased the shelf life of mango and papaya by ten and seven days, respectively (Kabir and Hossain, 2024).

Conclusion

Chitosan ameliorated the physicochemical properties of jujube, including shelf life. A 0.5% chitosan coating on Ball Sundori Kul resulted in minimum fruit weight loss, maximum fruit size, and highest retention of vitamin C, total flavonoids, and anthocyanins. The 0.5% chitosan also caused the lowest disease incidence and the highest shelf life. Therefore, 0.5% chitosan can be used for postharvest quality preservation of jujube, particularly Ball Sundori Kul. However, further research should be conducted before making a recommendation, as this study evaluated the attributes of jujube just once. Moreover, the effects of chitosan on other fruits should be evaluated.

Competing Interest

The authors report that there are no competing interests to declare.

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