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Effects of chitosan treatment on the texture parameters of okra fruit (*Abelmoschus esculentus* L. Moench)

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RESEARCH ARTICLE

Abstract

In recent years, due to its medicinal properties and reputation as a healthy vegetable, consumption of okra (*Abelmoschus esculentus* L.) has considerably increased in China. In this study, texture parameters (hardness, springiness, cohesiveness, gumminess, chewiness, and resilience) of okra fruit subjected to chitosan (CTS) treatment and control were determined during storage. The changing pattern of texture properties and the differences between three different cultivars (Kariba, ACF, and Xianzhi) were observed at three testing stages (0, 15, and 30 days of storage), which indicated a significant cultivar-dependent pattern. The hardness, cohesiveness, gumminess, chewiness, and resilience of the fruit, both in the 1% CTS treatment group and the control group, declined along with storage time. The small fruits (length < 10 cm) scored relatively low in most of the texture parameters and rate of intact when compared with large (length ≥ 15 cm) and medium-sized fruits (10 ≤ length < 15 cm). There was a significant, positive correlation between firmness, cohesiveness, gumminess, chewiness, and resilience. Our results revealed that a 1% N, O-carboxymethyl CTS solution can effectively delay softening and maintain the texture profile of the okra fruit. In the case of Kariba (A) and Xianzhi (C), the medium-sized fruits showed better storage resistance, while the large fruit of ACF (B) showed the best storage resistance.

Keywords: okra (*Abelmoschus esculentus* L. Moench); fruit, chitosan; texture profile analysis

1. Introduction

Okra (*Abelmoschus esculentus* L.), also known as ladies' fingers, belongs to the mallow family, and is a tropical annual herb. Okra is a healthy vegetable that is rich in protein and polysaccharides, and has a high nutritional value. Its fruit is tender, mucilaginous, flavorful, and easy to cook. It can also be canned and used to make kimchi (Chen, 2010). Owing to the high adhesiveness of the okra extract, it can be used as a fat substitute to make low-fat chocolate and cookies. The tissue of the okra fruit softens gradually during storage, and hence it is very important to maintain the quality of fruits during storage. At present, okra is mainly stored under refrigeration, and modified atmosphere combined with preservatives. Therefore, scientists have focused on research and technical development to extend the shelf-life of okra.

The concept of texture profile analysis (TPA) was developed more than 50 years ago. It was widely used to analyze a series of textural parameters in a single test by means of a double compression of the sample (Alvarez

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et al., 2002). The changes of texture properties from different fruit anatomies, such as tomato (Camps, 2017), grape (Rolle *et al.*, 2011), and blueberry (Giongo *et al.*, 2013), have been examined using the TPA test. Xie *et al.* (2018) reported that the 1-methylcyclopropene combined with commercial polyethylene bags can effectively maintain the texture properties of blueberry. Recently, texture parameters of the fruit of the Barhi date at different maturity stages were evaluated by near-infrared (NIR) spectroscopy, which is a powerful nondestructive tool that can be used to determine fruit quality attributes (Alhamdan *et al.*, 2019; Nicolaï *et al.*, 2006). Therefore, TPA has played an important role in evaluating the mechanical and physical characteristics of fruits, as well as raw ingredients and finished products (Sato and Yamada, 2003). Compared with other methods, the TPA test can provide multiple parameters simultaneously to reflect the physical properties of fruits.

The market price of the okra fruit varies greatly by season and region. The price of okra from a producing area is usually higher than that from a nonproducing area, and it is lowly priced in summer and highly priced in winter. For instance, its price can be 30–50 RMB per kilogram in the Guizhou province of China, which is significantly more expensive than common vegetables. But okra can only be grown in the tropics in winter. Due to the shorter fresh period of okra, its long distance transportation causes great economic losses. Effectively extending the shelf-life of okra could meet the growing demand for fresh products at home and abroad.

Previous studies have revealed that okra treated with N,O-carboxymethyl chitosan (CTS) could be stored for a long time to maintain its appearance and flavor (Alvarez *et al.*, 2002; Xie *et al.*, 2018). However, the texture changes in the okra fruit after treatment with N,O-carboxymethyl CTS are still unknown. In this study, texture degradation during storage has been investigated with regard to the okra fruit treated with CTS. The aim of this study was to uncover the degradation patterns of fruit texture in okra, which is useful for understanding its preservation mechanism.

2. Materials and methods

Materials

Three different cultivars of the okra fruit from three different areas of China—Kariba from the Jiangsu province, ACF from the Hebei province, and Xianzhi from the Zhenjiang province—which were labeled as A, B, and C, respectively, were used to determine the TPA texture parameters of the fruit. The agronomic traits of the fruits from three different cultivars are shown in Table 1. The fruits were classified into three classes according to size, including large (L ≥ 15 cm in length) marked as 1, medium (10 cm ≤ L < 15 cm) marked as 2, and small (L < 10 cm) marked as 3. In general, the longer the length of the fruit, the greater its diameter, and the heavier its weight. Okra can be five-sided up to eight-sided, depending on the cultivar. The color of the fruit in Kariba (A) and Xianzhi (C) is both green, while that of ACF (B) is white.

Methods

Three different cultivars of okra were planted in an experimental field in Zunyi, China, in April 2018. The okra fruit was harvested in August 2018. The fruits of the three okra cultivars were further divided into three classes according to their size (large, medium, and small). A total of 18 fruits were selected from each class of the cultivar, and half of them were treated with CTS (the treatment group) and the remaining half were not treated (the control group). In total, there were 162 samples in this study. The fruit was processed immediately after

Table 1. Agronomic trait of the fruit.

Cultivar	Size	Length (cm)	Diameter (cm)	Weight of each fruit (g)	Sides	Fruit color
A (Kariba)	Large	15.89	2.51	36.73	5	Green
	Medium	13.69	2.18	24.22	5	Green
	Small	9.04	2.41	15.91	5	Green
B (ACF)	Large	18.12	3.14	34.57	8	White
	Medium	14.09	3.07	33.09	8	White
	Small	9.21	2.58	31.37	8	White
C (Xianzhi)	Large	21.65	2.12	37.89	5	Green
	Medium	16.89	2.10	31.25	5	Green
	Small	12.36	1.68	16.91	5	Green

harvesting. The TPA texture parameters of the fruit were determined before treatment, including hardness, cohesion, gumminess, chewiness, and resilience.

Okra fruits were soaked in an N, O-carboxymethyl CTS solution with mass fraction of 1% for 1 min according to Li *et al.*'s (2015) method. The solution was completely infiltrated into the epidermis. The samples were removed from the soaking solution, wrapped in a plastic bag, and stored in a refrigerator at 4°C. The controls were also wrapped in a plastic bag and stored at 4°C. There were a total of three biological replicates in our study. The texture parameters of each sample were evaluated after 15 days and 30 days, respectively. Meanwhile, the amount of rotten fruit was investigated, and the rate of good fruit was calculated according to Li *et al.*'s (2011) method.

The TPA was implemented according to Li *et al.*'s (2011) method. The okra fruit was carefully peeled (without lifting the flesh) and placed on the flat plate of a Texture Analyser (TA)—XT*Plus* (Stable Micro Systems, Surrey, UK). Then, TPA was carried out with a cylindrical probe P/75 with a diameter of 75 mm. The evaluation parameters were the following: pretest velocity, 5 mm/s; test velocity, 2 mm/s; posttest ascending velocity, 2 mm/s; pulp deformation, 25% under compression; pause time of two compressions, 5 s; trigger force, 5 N (Li *et al.*, 2011).

3. Results

Changes in okra fruit hardness during storage

Hardness reflects the external force required for okra fruit deformation. Figure 1 shows that the hardness of the okra fruit, both in the CTS treatment group and the control decreased with the extension of storage time. The control was completely rotten and could not be measured at 30 days of storage. The hardness of the fruit treated with CTS decreased at a much slower rate than that of the control. In particular, the hardness of the large fruit from Kariba (A) treated with CTS at 15 days of storage was significantly higher than that of others at the same storage time, which was slightly lower than the original at 0 days of storage. During the entire storage period, ACF (B) had the highest hardness in the large fruit and the lowest hardness in the small fruit under both the CTS treatment and the control conditions. However, the changes of fruit hardness from Kariba and Xianzhi varied with the extension of storage. The hardness of the large fruit both in Kariba (A) and Xianzhi (C) were highest at 0 days of storage, and that of the medium fruit treated with CTS was highest at 30 days of storage. There were no significant differences in hardness between the medium fruit and the small fruit both at 0 and 15 days of storage, except for Xianzhi (C) treated with CTS at 15 days of storage. For

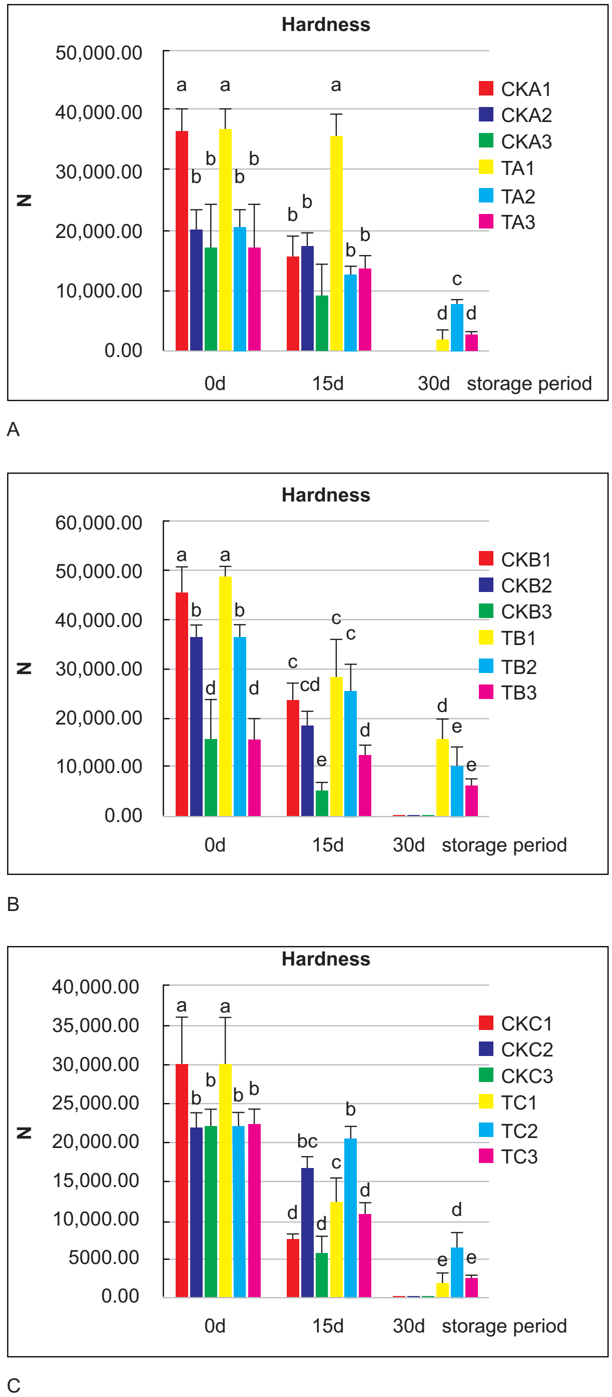


Figure 1. Hardness of the okra fruit in the chitosan treatment groups and the control groups during storage. A: Kariba, B: ACF, C: Xianzhi.

Note: CKx was representative of the control group, and Tx was representative of the chitosan treatment group. 1: large, 2: medium, 3: small. The same letters indicate no significant difference at the level of 0. 05 (the same below)

Kariba (A) and Xianzhi (C), the hardness of the medium fruit was the highest compared with others when treated with CTS for 30 days.

Changes in okra fruit resilience during storage

Resilience is defined as the ability of a sample to bounce back during the first compression. Due to fruit decay in the control, the data at 30 days of storage could not be obtained. As shown in Figure 2, the resilience of the fruit, for both the CTS treatment and control, showed a decreasing trend with the extension of storage time. The differences between the fruit treated with CTS and the control were not remarkable. The three cultivars of okra exhibited various changing resilience trends during storage. Kariba (A) had the highest resilience in small fruit at 0 days of storage, whereas there were no significant differences between all of the treatments and the control. ACF (B) had the highest resilience in large fruit at 0 days of storage. Only the resilience of large fruit treated with CTS was significantly higher than that of the control at 15 days of storage, while others had no significant difference. The resilience of Kariba (A) and ACF (B) at 30 days of storage was shown to have no significant difference between large, medium, and small fruits. For resilience of Xianzhi (C), there were also no significant differences between the different sizes at 0 days of storage. Like ACF (B), the resilience of large and medium fruit treated with CTS was significantly higher than that of the control at 15 days of storage, while others had no significant difference. Xianzhi (C) had the highest resilience in large fruit treated with CTS at 30 days of storage, while it had no significant difference with that of small fruit.

Changes in okra fruit cohesion during storage

Cohesion refers to the internal adhesion of the pulp against the destruction from teeth when chewing, which reflects the degree of intercellular adhesion in pulp. The data of the control at 30 days of storage could not be obtained because the fruit was completely rotten. Figure 3 shows that the cohesion of the fruit in both CTS treatments and the controls declined along with increase of storage time. However, for Kariba (A) and Xianzhi (C), the differences between the CTS treatments and controls were not remarkable at the test point of 15 days of storage. The three cultivars of okra exhibited various cohesion trends during storage. The cohesion of the small fruit in Kariba (A) was the highest at 0 days of storage, while no significant differences between the three different sizes of the fruit with CTS treatment was observed at 30 days of storage. ACF (B) had the highest cohesion in large fruit at 0 days of storage. Also, it also had the highest cohesion in large fruit treated with CTS at 15 days of

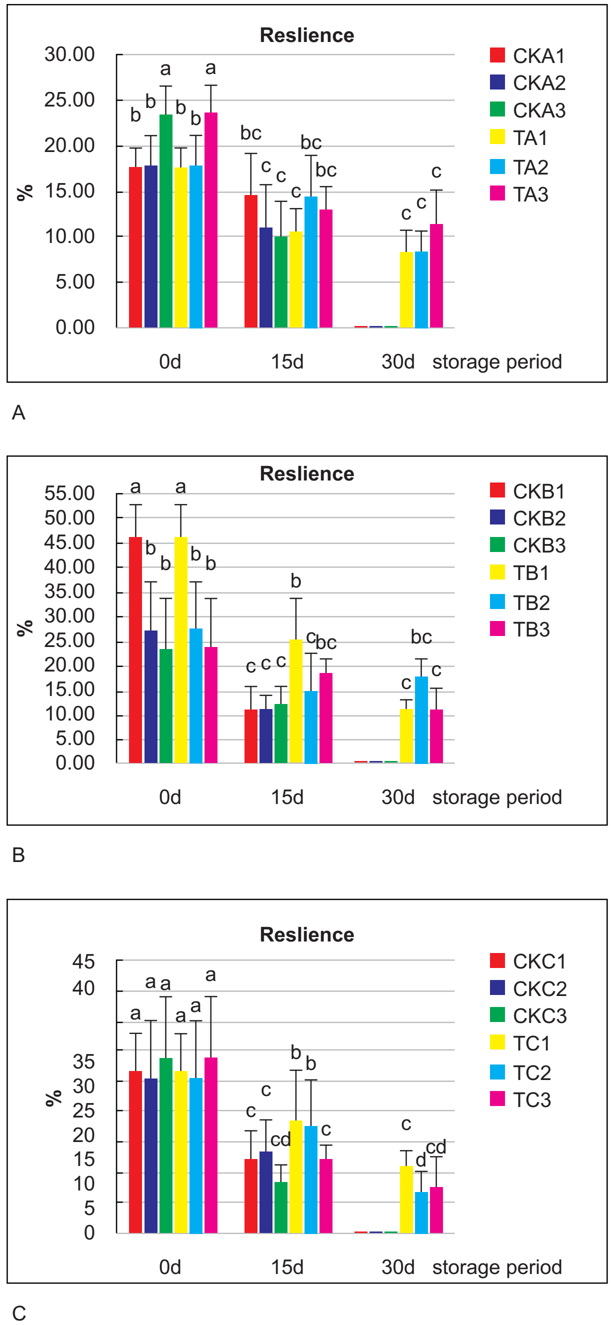


Figure 2. Resilience of the okra fruit during storage. A: Kariba, B: ACF, C: Xianzhi.

storage, which was significantly higher than that of the others. For the treatment in ACF (B), the differences of cohesion between large and medium fruits were not remarkable, while they were significantly higher than that of small fruit. For Xianzhi (C), there were no significant differences between the three different sizes of fruit at 0 days and 30 days of storage. Only the cohesion of small fruit treated with CTS was significantly higher than that of the control at 15 days of storage.

Changes in okra fruit springiness during storage

Springiness is the degree to which pulp can recover after the first compression deformation under the condition of removing the deformation force. The data of the control at 30 days of storage could not be obtained because the fruit was completely rotten. As shown in Figure 4, the springiness of the fruit treated with CTS exhibited an increasing trend along with storage time, while the control showed a decreasing trend. And, the differences between the treatment groups and the control were not remarkable. During the same storage period, there were no significant differences between the three different sizes of fruit both in the treatment and control groups. The springiness of the small fruit in the control from Kariba (A) and Xianzhi (C) were significantly lower than others at 15 days of storage, which implies that storage has more impact on springiness of the small fruit compared with other sizes.

Changes in okra fruit gumminess during storage

Gumminess is the product of hardness and cohesiveness. Due to fruit decay in control, the data at 30 days of storage could not be obtained. Figure 5 shows that gumminess of the okra fruit in both the CTS treatment group and control increased along with storage time. The changes in fruit gumminess of the three cultivars were varied during storage. The gumminess of the large fruit in Kariba (A) had no significant difference with that of the small fruit, which was significantly higher than that of the medium fruit at 0 days of storage. However, only the gumminess of the large fruit treated with CTS was significantly higher than that of the corresponding control at 15 days of storage. Kariba (A) had the highest gumminess in medium fruit treated with CTS at 30 days of storage. ACF (B) had the highest gumminess in large fruit and the lowest gumminess in small fruit under both the CTS treatment and control conditions during storage. Xianzhi (C) had the highest gumminess in large fruit treated with CTS during storage, which exhibited different changing trends in comparison to that of the control.

Changes in okra fruit chewiness during storage

Chewiness refers to the amount of energy required to chew a solid sample into a stable state of swallowing. It comprehensively reflects the continuous resistance of pulp to external forces in the process of chewing. Due to fruit decay in the control, the data at 30 days of storage could not be obtained. Figure 6 shows that the chewiness of the okra fruit in both the CTS treatment group and control decreased along with an increase in storage time. The differences between the CTS treatment and control

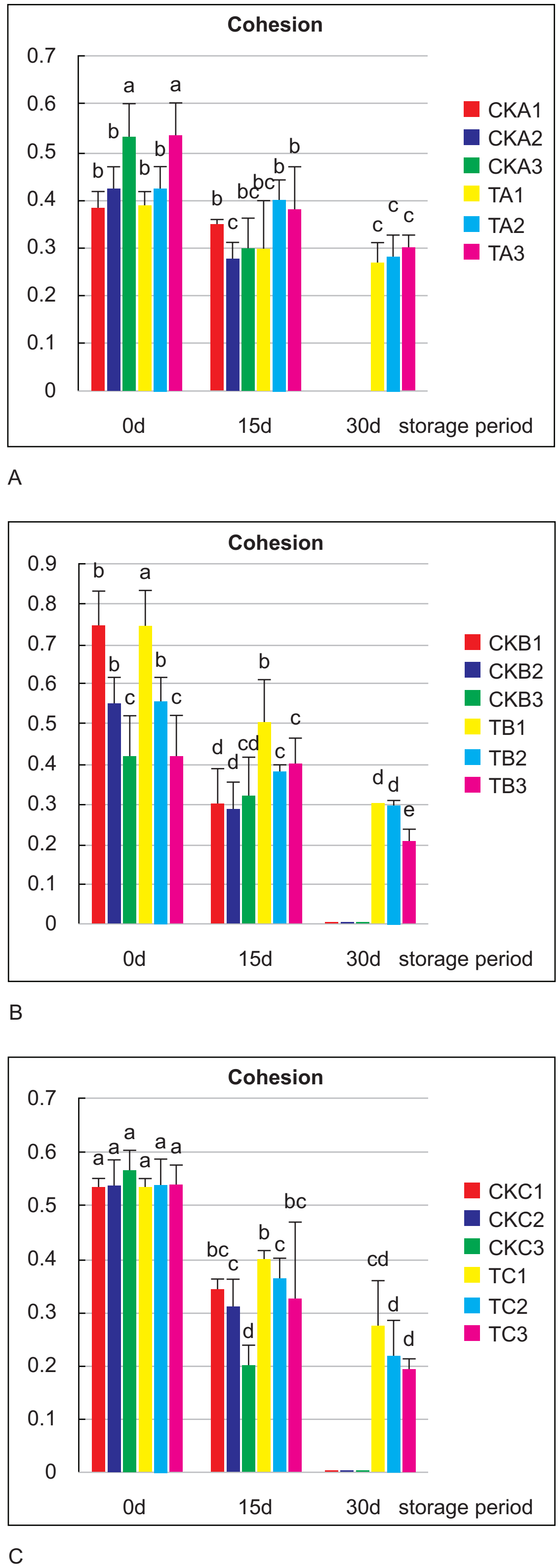


Figure 3. Cohesion of the okra fruit during storage. A: Kariba, B: ACF, C: Xianzhi.

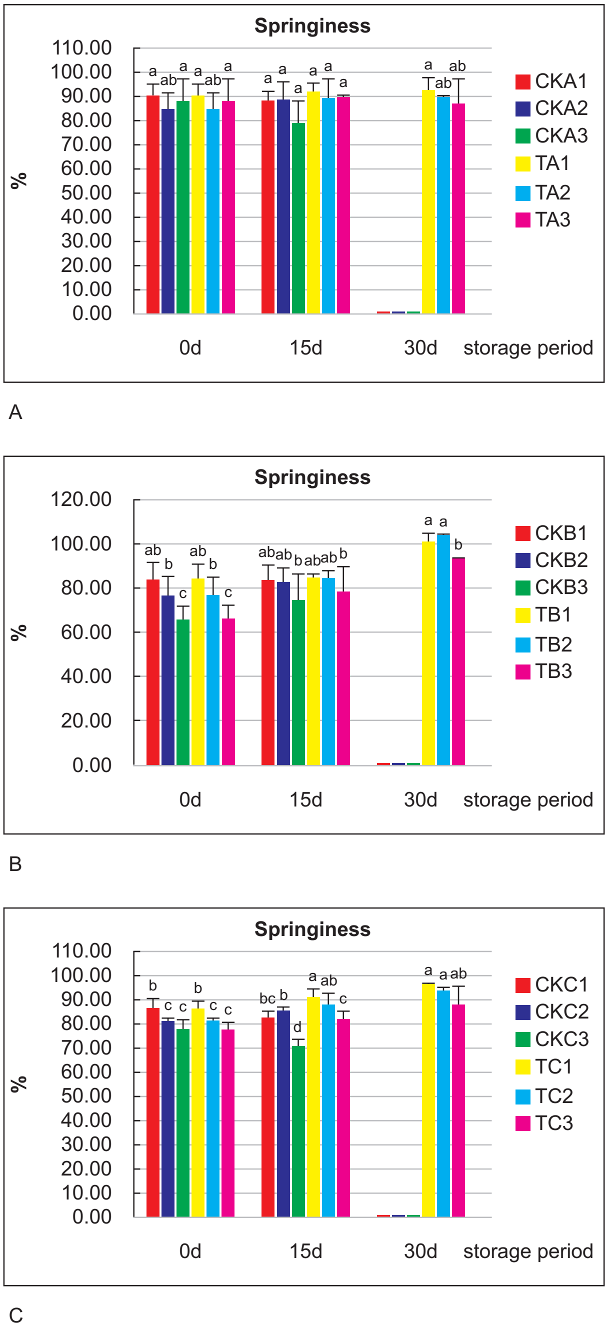


Figure 4. Springiness of the okra fruit during storage. A: Kariba, B: ACF, C: Xianzhi.

in ACF (B) were remarkable at 15 days of storage, while others were not. Three cultivars of okra exhibited different changing trends of fruit chewiness during storage. Kariba (A) had the lowest chewiness in medium fruit at 0 days of storage, which was not significantly lower than that of large and small fruits. However, only the chewiness of the small fruit treated with CTS was significantly higher than that of the corresponding control at 15 days of storage. Kariba (A) had the highest chewiness in medium fruit and the lowest chewiness in small fruit

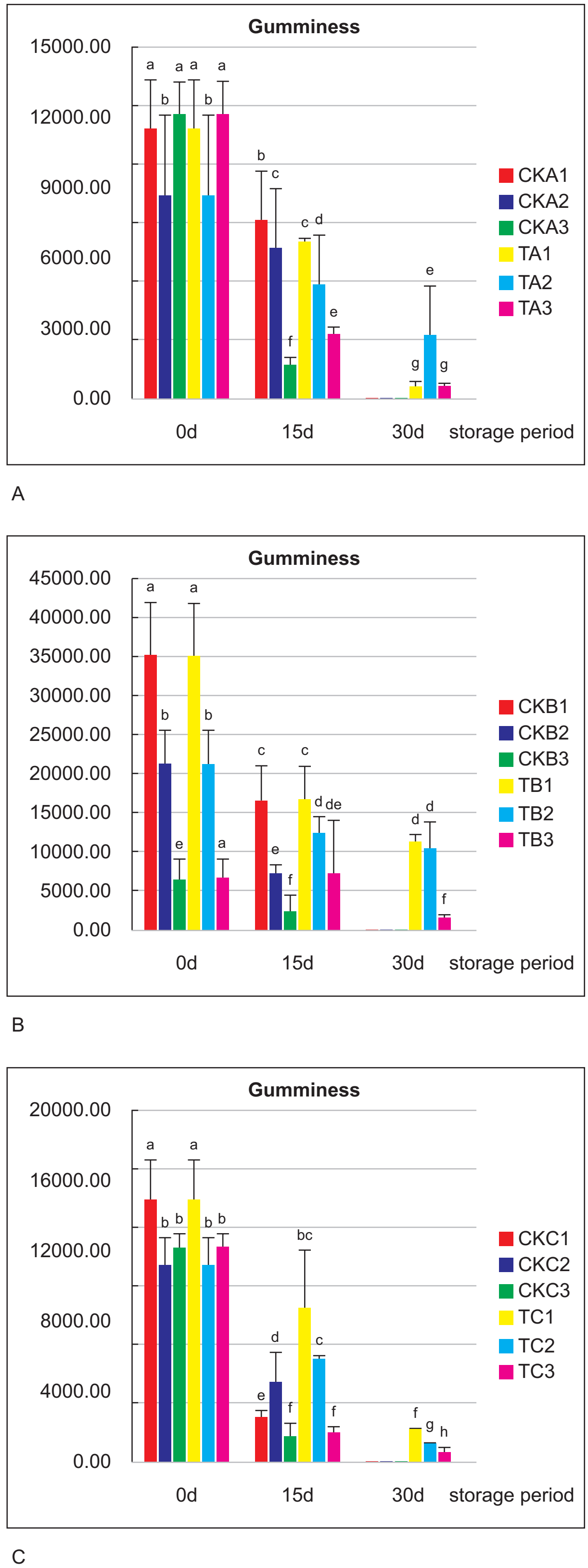
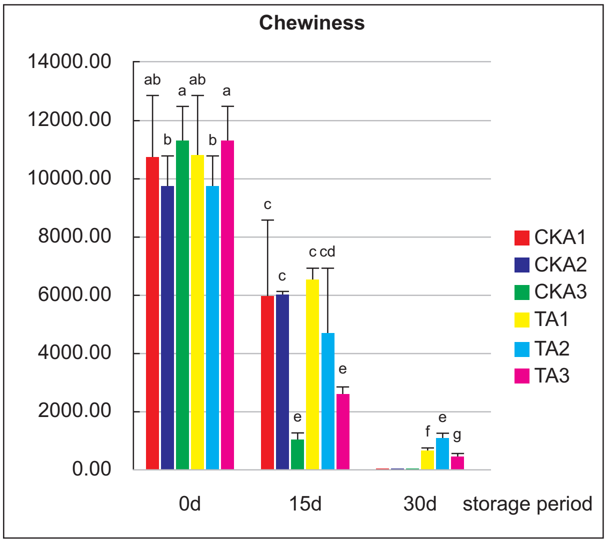
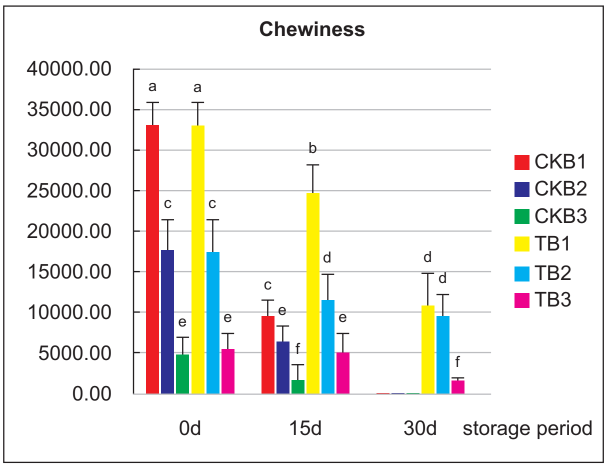


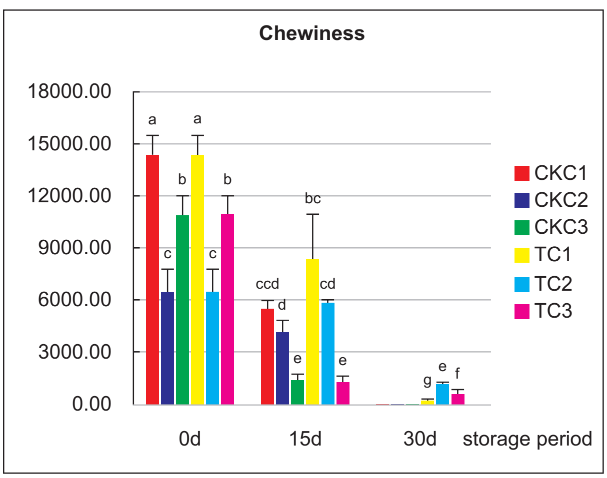
Figure 5. Gumminess of the okra fruit during storage. A: Kariba, B: ACF, C: Xianzhi.



A



B



C

Figure 6. Chewiness of the okra fruit during storage. A: Kariba, B: ACF, C: Xianzhi.

treated with CTS at 30 days of storage. ACF (B) had the highest chewiness in large fruit and the lowest chewiness in small fruit under both the CTS treatment and control conditions during storage. For Xianzhi (C), the chewiness of the large fruit both in the CTS treatment group and control were the highest compared with medium and small fruits at 0 and 15 days of storage, while that of the large fruit treated with CTS was the lowest at 30 days of storage.

Correlation analysis of texture parameters

Correlation of various parameters obtained by the TPA test is shown in Table 2. Hardness had a significant positive correlation with resilience, cohesion, gumminess, and chewiness under the storage conditions ($P < 0.05$). The resilience of the fruit presented a significant positive correlation with cohesion and gumminess ($P < 0.01$), indicating that the higher the resilience of the fruit, the higher is its cohesion and gumminess. Furthermore, the resilience of the fruit also displayed a significant correlation with chewiness ($P < 0.05$). Adhesion is positively correlated with springiness. Cohesion of the fruit presented a significant positive correlation with gumminess and chewiness ($P < 0.01$), which implies that the higher the cohesion of the fruit, the higher is its gumminess and chewiness. Gumminess of the fruit presented a significant positive correlation with chewiness ($P < 0.01$), suggesting that the higher the gumminess of the fruit, the higher is its chewiness.

Effect of chitosan treatment on the rate of intact fruit during storage

The rate of intact fruit both in the CTS treatment group and control significantly decreased along with storage time (Table 3). The decreasing amplitude of the intact fruit rate in the treatment was significantly less than that of the control. For the CTS treatment group, the rate of intact fruit in the large fruit of Kariba (A) was the highest at 15 day of storage. Kariba (A) and Xianzhi (C) had the highest rate of intact fruit in the medium fruit treated with CTS in comparison with large and small fruits at 30 days of storage, while ACF (B) had the highest rate of intact fruit in the large fruit. The control was completely rotten at 30 days of storage.

4. Discussion

In this work, we found that CTS treatment delayed the decline of hardness, chewiness, and resilience of okra fruit, and helped to maintain cohesion for a small range and a high level during storage, which was consistent with the results in blueberry (Xie *et al*., 2018) and date fruits of *Phoenix dactylifera* L. (Alhamdan *et al*., 2018). Moreover, the average rate of intact fruit of the three cultivars was 20.05%, while the control was completely decayed at 30 days of storage. These results indicated that a 1% N,O-carboxymethyl CTS solution delayed the softening of the okra fruit. N,O-carboxymethyl CTS has good film formation, which not only has a selective permeability of gas but is also anti-bacterial (Chen, 2010). The possible reason for the delayed softening is that compared with the control, the intercellular binding force and the integrity of the tissue structure were increased in the presence of film protection. Thus, both intercellular adhesion and tissue integrity were increased, which slowed down the decline in some texture parameters of the fruit, which in turn delayed softening (Li *et al.*, 2011). Furthermore, CTS treatment has a clear effect on the springiness changes in okra fruit during storage, which was inconsistent with the results in grape (Li *et al*., 2011b) and pear (Wang *et al*., 2013). This is likely due to differences in the preservation treatments and may also be associated with the physiological properties of the okra fruit.

Shi *et al*. (2019) found that the graft copolymer (CTS-g-SA) of CTS and salicylic acid (SA) retained fruit firmness without impairing grapefruit fruit quality and significantly suppressed green mold caused by Penicillium digitatum during postharvest storage. CTS has been reported to enhance the bacteriostatic activity of other preservatives, such as benzoate, phenylmercuric acetate, phenethyl alcohol, and benzoic acid (Duan *et al*., 2019). It is suggested that a lot of complex postharvest techniques should be applied to keep the okra fruit fresh and delay softening in the future. Different fruit preservation strategies should be employed according to their texture parameters.

The TPA test can obtain such parameters as hardness, springiness, cohesiveness, gumminess, chewiness, adhesiveness, and resilience. Adhesiveness is mostly used to evaluate texture properties of semisolid samples. Okra is a solid fruit, so the adhesiveness parameter was not analyzed in our study. According to the correlation analysis, parameters of hardness, resilience, cohesion, gumminess, and chewiness can be employed to evaluate the texture profile of the okra fruit. The results are similar to the report from Rabbiteye blueberry (Xie *et al*., 2018), grape (Tian *et al*., 2011), and apple (Jia *et al*., 2014).

There was no consistent variation between fruit size and texture parameters of the three cultivars. We also found that hardness, gumminess, and chewiness of the large fruit are the highest compared with medium and small fruits at 0 days of storage, except for Kariba (A). The hardness and rate of intact fruit in the medium fruit are the highest compared with large and small fruits stored for 30 days, except for ACF (B). Okra fruits with different sizes have different trends of change of texture parameters during storage. For some cultivars, large-sized fruit is more resistant to storage. For others, medium-sized fruit is the most durable. Giongo *et al*. (2019) found that the fruit size of raspberry is significantly and positively correlated with compression measurements. However, our study showed that most of the parameters and the rate of intact fruit of the small fruit were relatively low in comparison to that of large and medium fruits. The possible reason is that the small fruit is more tender and less fibrous. In contrast, larger, more fibrous, fruit has a stronger structure and is suitable for picking and long-term storage (Giongo *et al*., 2019). If a fruit is too fibrous like the larger fruit, its taste and flavor will decrease in comparison with the smaller fruit. The fresh weight of each fruit, sizes, and firmness of the okra fruit are considered as the significant indicators for maturation (Petropoulos *et al*., 2018). Numerous studies have demonstrated that the length of the okra fruit was regarded as the most important index for harvesting (Olivera *et al*., 2012). The harvesting period was significantly varied between different cultivars. It implies that taste and storage resistance

Table 2. Correlation (R) among texture parameters of the okra fruit from TPA.

Parameter	Hardness	Resilience	Adhesiveness	Cohesion	Springiness	Gumminess	Chewiness
Hardness	1						
Resilience	0.666*	1					
Adhesiveness	–0.168	–0.361	1				
Cohesion	0.653*	0.965**	–0.243	1			
Springiness	–0.201	–0.421	0.697*	–0.365	1		
Gumminess	0.638*	0.858**	–0.032	0.869**	–0.046	1	
Chewiness	0.523*	0.774*	0.069	0.805**	0.041	0.960**	1

Note: * $P < 0.05$, ** $P < 0.01$.
TPA, texture profile analysis.

Table 3. The rate of intact fruit during storage.

Storage		0 days	15 days	30 days
CK	A1	100.00 a(a)	28.82 b(g)	0.00 c(e)
	A2	100.00 a(a)	39.22 b(f)	0.00 c(e)
	A3	100.00 a(a)	15.83 b(i)	0.00 c(e)
	B1	100.00 a(a)	53.33 b(d)	0.00 c(e)
	B2	100.00 a(a)	48.31 b(e)	0.00 c(e)
	B3	100.00 a(a)	20.19 b(h)	0.00 c(e)
	C1	100.00 a(a)	28.12 b(g)	0.00 c(e)
	C2	100.00 a(a)	45.37 b(e)	0.00 c(e)
	C3	100.00 a(a)	26.82 b(g)	0.00 c(e)
T	A1	100.00 a(a)	84.82 b(a)	17.17 c(c)
	A2	100.00 a(a)	40.38 b(f)	25.43 c(b)
	A3	100.00 a(a)	43.03 b(ef)	14.05 c(cd)
	B1	100.00 a(a)	68.85 b(c)	36.82 c(a)
	B2	100.00 a(a)	54.82 b(d)	23.36 c(b)
	B3	100.00 a(a)	37.82 b(f)	15.27 c(c)
	C1	100.00 a(a)	46.82 b(e)	10.14 c(d)
	C2	100.00 a(a)	77.35 b(b)	25.09 c(b)
	C3	100.00 a(a)	47.94 b(e)	13.13 c(cd)

Note: Within a row, the same letters outside the brackets indicate no significant difference at the significance level of 0.05. Within a column, the same letters inside brackets indicate no significant difference at the significance level of 0.05.

should be taken into account to determine the appropriate harvesting length of the okra fruit.

5. Conclusion

Our results suggest that a 1% N,O-carboxymethyl CTS solution can effectively delay softening and maintain texture profiles of the okra fruit. Also, the small fruit may display poor storage stability compared with that of large and medium fruits.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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