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Full Length Research

Comparison of two storage conditions on the electrical and mechanical properties of okra *(Abelmoschus esculentus)* pods

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ABSTRACT: This research studied the influence of storage conditions on the mechanical and electrical parameters of okra (*Abelmoschus esculentus*) pods. In this study, the okra pods were stored in two conditions - ambient condition (32±3˚C and 87±6% RH) and refrigerated condition (10ºC and 65% RH), and strength parameters (failure force, failure energy, rupture force and rupture energy, and electrical properties (electrical conductivity and resistivity) were evaluated in three day interval for nine consecutive days (0, 3, 6, and 9 d). All the tests were conducted in accordance with American Society for Testing and Materials (ASTM) International procedures. Results from the research indicated that storage duration had a significant ($p \leq 0.05$) effect on all the parameters investigated. The rupture energy and electrical resistivity of the ambient batch inclined from 0.17 to 1.09 Nm and 2.653 to 3.356 Ωm, respectively; whereas, in the refrigerated batch**,** the rupture energy and electrical resistivity increased from 0.17 to 0.34 Nm and 2.653 to 2.841 Ωm, respectively. Notably, the electrical conductivity declined from 0.377 to 0.298 S/m and from 0.377 to 0.352 S/m, for the ambient and refrigerated conditions, respectively. Remarkably, the information gathered from this study will be helpful in automated okra pod integrity monitoring and the design and production of smart okra pod packaging structures.

Keywords: Automated unit, electrical accessories, ruptured point, storage, strength properties.

INTRODUCTION

Okra (*Abelmoschus esculentus*), which belongs to the Malvaceae family, is one of the most cultivated and utilised species of the family. The plant has numerous industrial and medicinal applications; okra products are used as fibres, pharmaceutical essential oils, biodegradable electronic parts and biosensors. Medicinally, it is utilised as a blood volume expander or plasma replacement (El-Shaieny *et al.,* 2022). The engineering properties of biomaterials are dependent on their respective maturity age, moisture content level and storage conditions. These properties of agricultural products basically influenced their electrical properties, physical characteristics, mechanical and thermal performances (Santos *et al*., 2020; Todros *et al*., 2021). Traditional skills are still widely applied during okra pods' harvesting and handling unit operations; harvesting is mainly by manual approach. This makes the tasks difficult due to irregularities in the maturity age and physical properties of the okra pods. Remarkably, adequate knowledge of okra engineering properties will enhance their utilisation in different industrial sectors. The behaviours of these properties, under different conditions, are essential for the design, production and performance of machines, as well as electrical/electronic components (Stawski *et al*., 2020).

Many scholars have conducted intensive research into the mechanical and electrical properties of fruits and vegetables (Nyorere and Uguru, 2018; Banti, 2020; Stawski *et al*., 2020; El-Shaieny *et al.,* 2022; Afraz *et al*., 2024). The strength properties of agricultural materials facilitate the design and production of on-harvesting and handling machinery. Prasad and Kumar (2014) observed wide variation in the electrical conductivity (EC) values of different plants, and this EC substantially affects their nutrient qualities and engineering applications. According to Assawarachan and Tantikul (2025), the EC values of agricultural materials affect their stability, as well as their minerals and sugars concentration; and these conditions can be attributed to the larger salt proportions linked to elevated EC levels (Afraz *et al*., 2024). Nyorere and Uguru (2018) investigated the impact of maturation on cucumber fruit's mechanical properties and reported that the ageing period influenced the textural behaviours of cucumber fruits. Zia *et al.* (2024) reported that adequate information on food product EC values gives an insight into their nutritional integrity, design and development of their automated production system.

Remarkably, information provided by scholars has depicted that adequate knowledge on the electrical and mechanical parameters of agri-products facilitates the full automation of agricultural production and utilisation of farm produce. Therefore, the principal goal of the present research was to evaluate the impact of storage conditions on the electrical and mechanical properties of okra pods. Results obtained from this study will give insights into the production of advanced food processing approaches and the development of electronic components from okra products.

MATERIALS AND METHODS

Sample preparation

The matured okra pods were harvested from Southern Delta University, Ozoro, Delta State, Nigeria. The specimens were selected based on size consistency, appearance and healthy state; thereafter, they were divided into two groups. One set was kept under ambient environmental conditions (32±3˚C and 87±6% RH), and the other lot was stored inside a refrigerator (10°C and 65% RH). This cooling temperature was recommended by Watkins and Nock (2012) for okra pods. For each experiment, the refrigerated sample was left for 2 hours to equilibrate with room temperature (Coskun *et al*. 2005). Subsequently, the pod's mechanical and electrical properties were evaluated at the three-day intervals (0, 3, 6 and 9 days), starting from the sampling day.

Laboratory evaluation

Compression characteristics

The pods compressive parameters were determined by following the ASTM International procedures, by using the Universal Testing Machine (Testometric model, series 500-532), equipped with a 100 KN force capacity and a maximum speed of 500 mm/min/. Each pod was compressed using a 25 mm/min speed to the rupture point. These compressive parameters - failure force, failure energy, rupture force and rupture energy- were mined through the Testometric software of the machine (Uguru and Nyorere, 2019).

Electrical properties

The electrical conductivity (EC) of the okra pod was determined by using the procedures explained by Banti (2020). Then the electrical resistivity (ρ) was calculated through Equation 1 (Knirsch *et al.,* 2010).

$$\rho = \frac{1}{EC} \quad (1)$$

Statistical analysis

Analysis of Variance (ANOVA) was employed to evaluate the effects of the storage conditions, on the mechanical and electrical properties of the okra pods examined.

RESULTS AND DISCUSSION

Effect of storage conditions on the mechanical properties

The results of the mechanical parameters of the okra pod are presented in Table 1. From the ANOVA table, storage duration and condition had a significant impact on the compressive strength parameters investigated ($p \leq 0.05$).

Effect of storage on the failure force

Figure 1 presents the consequences of storage conditions on the failure force (FF) of the okra pods. Notably, there was an uneven increment in the FF, regardless of the storage condition. Regression correlation between failure force and storage duration is expressed by the linear comparisons presented in Equations 2 and 3. The regression equations further illustrated the strong correlation between storage duration and the okra pod's FF value. Figure 1 depicts that the pods kept at room temperature developed a 65.82% increment in their FF, while the pods kept under refrigerated conditions had an 11.1% increment in their FF values. These findings are similar to those reported by Oghenerukewve and Uguru (2018) during their research on the influence of storage duration on the farm produce engineering properties. The increment in the pods FF as storage duration progresses can be associated mainly with moisture loss from the pods;

Table 1. ANOVA of the compressive parameters.

Source	df	FF	Rupture force	Failure energy	Rupture energy
T	3	5.85E-07*	5.56E-07*	5.85E-13*	1.08E-13*
C	1	2.63E-09*	7.28E-09*	8.81E-13*	1.48E-13*
T x C	3	0.00905*	0.00873*	4.2E-07*	4.6E-07*

* = significantly different at 5%, ns = not significantly different at 5%, T = storage duration; C = storage condition, FF = failure force, df = degree of freedom.

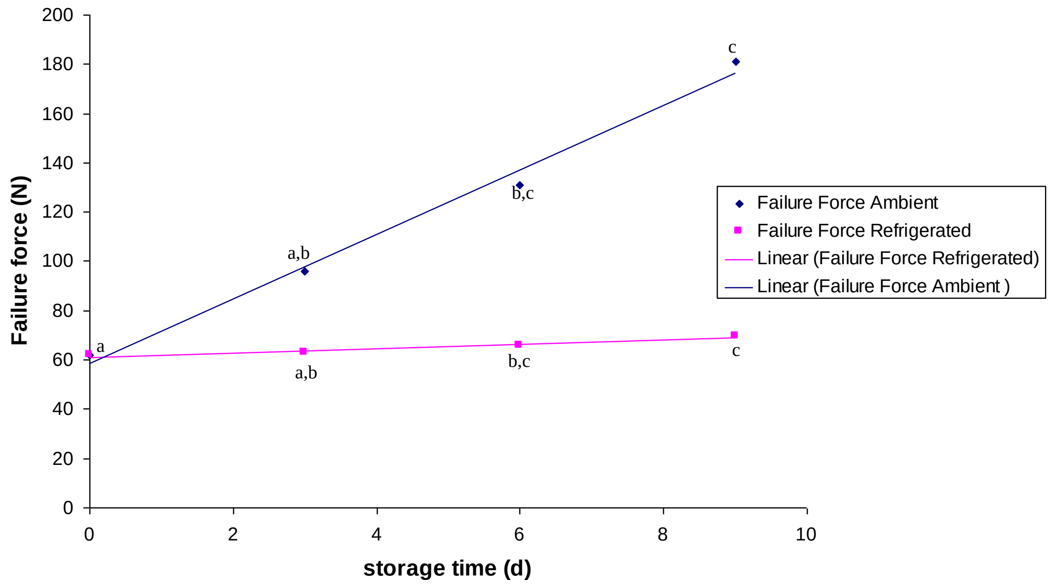

Figure 1. Influence of storage conditions on okra pod's failure force. For each line, the same letters represent non-statistical differences ($p < 0.05$), according to DMRT.

thereby, causing their cellular structure to stiffly up (El-Shaieny *et al.,* 2022).

$$F_{fa} = 13.07x + 58.585 \qquad R^2 = 0.9907 \qquad (2)$$

$$F_{fr} = 0.8663x + 61.124 \qquad R^2 = 0.9505 \qquad (3)$$

Failure energy (FE)

The results of the research's FE values are presented in Figure 2. It was observed that the pod's FE increased significantly (but in a non-uniform pattern) with increasing storage duration ($p < 0.05$). The regression relationship between failure energy and storage duration was expressed by Equations 4 and 5. The coefficient of determination results revealed that there was a perfect relationship prevailing between the storage duration and the FE. The FE increment was considerably higher in the ambient storage (88.14% increased), when compared to the refrigerated storage (36.4% increased). This is an indication that there was a rapid failure energy improvement in ambient storage than in refrigerated conditions. This situation can be linked to the stiffness of the pod's cellular structure, which occurs through rapid moisture loss from the cell structure (Eboibi and Uguru, 2018).

$$E_{fa} = 0.115x + 0.05 \qquad R^2 = 0.9454 \qquad (4)$$

$$E_{fr} = 0.01x + 0.145 \qquad R^2 = 0.9783 \qquad (5)$$

Rupture force (RF)

Figure 3 shows the results of the pods RF under the two storage conditions. It was observed that the RF values increased significantly during storage, regardless of the storage condition ($p \leq 0.05$). The RF tends to increase by 66.37% in the pods stored under the ambient condition, and 14.65% in the pods preserved under the refrigeration condition. The low rupture force at harvest may be because of the higher moisture content of the pod on harvest day, making the pod softer and requiring less force to rupture (El-Shaieny *et al.,* 2022).

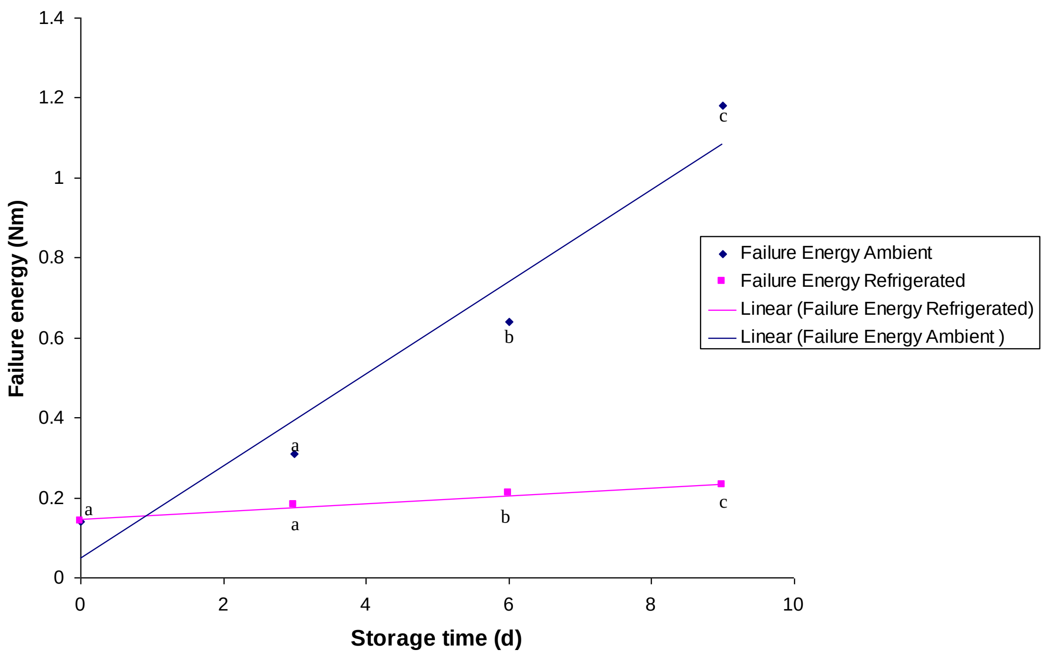

Figure 2. Impact of storage conditions on the FE of okra pods. Similar letters within the same line is an indication that the mean values are not statistically different, using the DMRT at p<0.05.

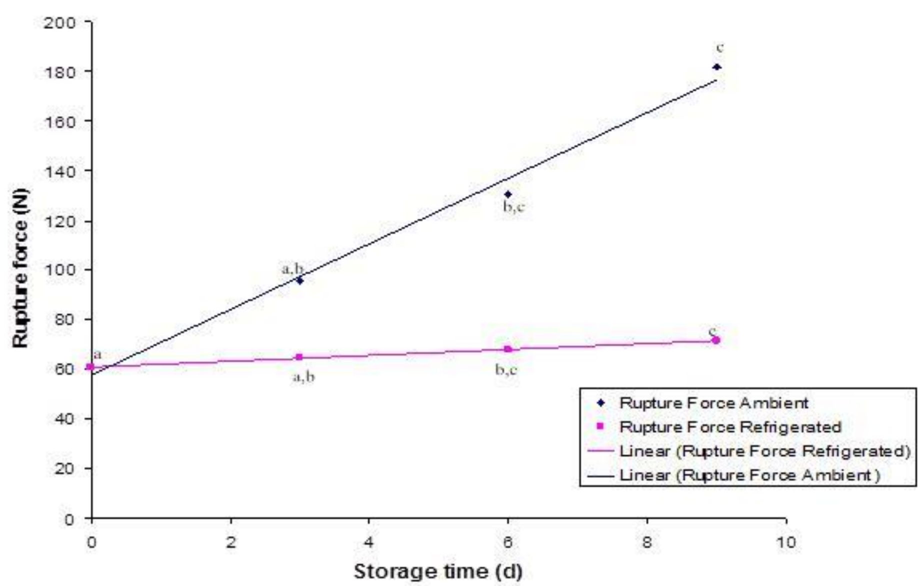

Figure 3. The pod's RF with respect to the storage conditions. Different letters within the same line signifies statistical differences ($p < 0.05$) using DMRT.

Rupture energy (RE)

The results of the pods' RE, with respect to the storage duration, are presented in Figure 4. Remarkably, the rupture energy of the pod at the storage duration showed a significant ($p \leq 0.05$) change in both storage conditions. The pods displayed an RE that increased from 0.17 to 1.09 Nm in the ambient condition experimental unit; whereas, in the refrigerated storage condition, the pods exhibited a much slower increment, with the pod's RE increasing from 0.17 to 0.34 Nm. Previous investigation outcomes have indicated that the mechanical parameters of agricultural products change during storage mainly due to moisture loss through transpiration, evaporation and physiological

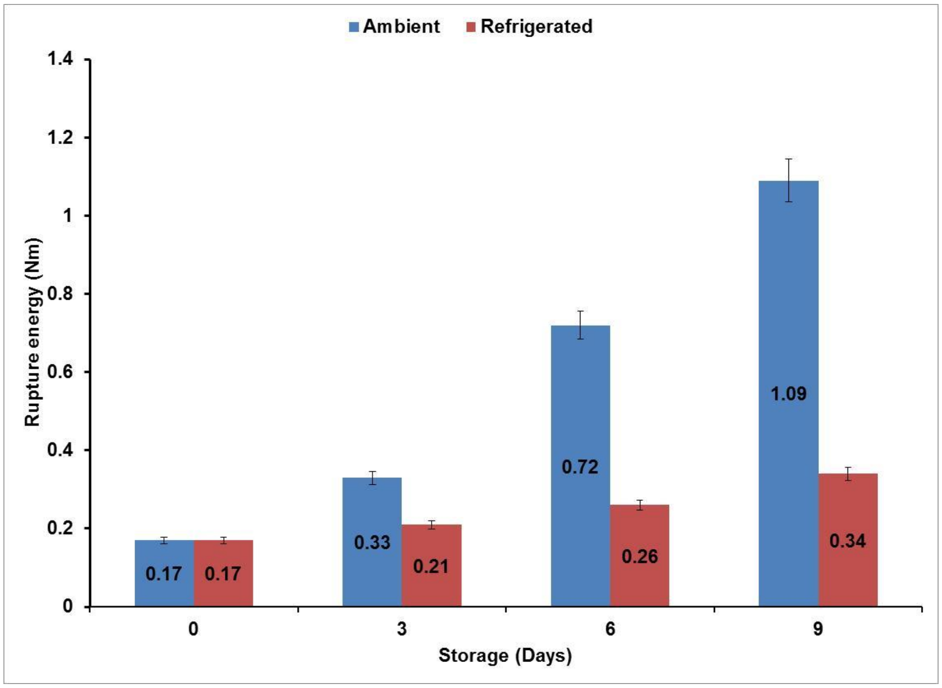

Figure 4. Effect of time and condition on the rupture energy of the okra pod.

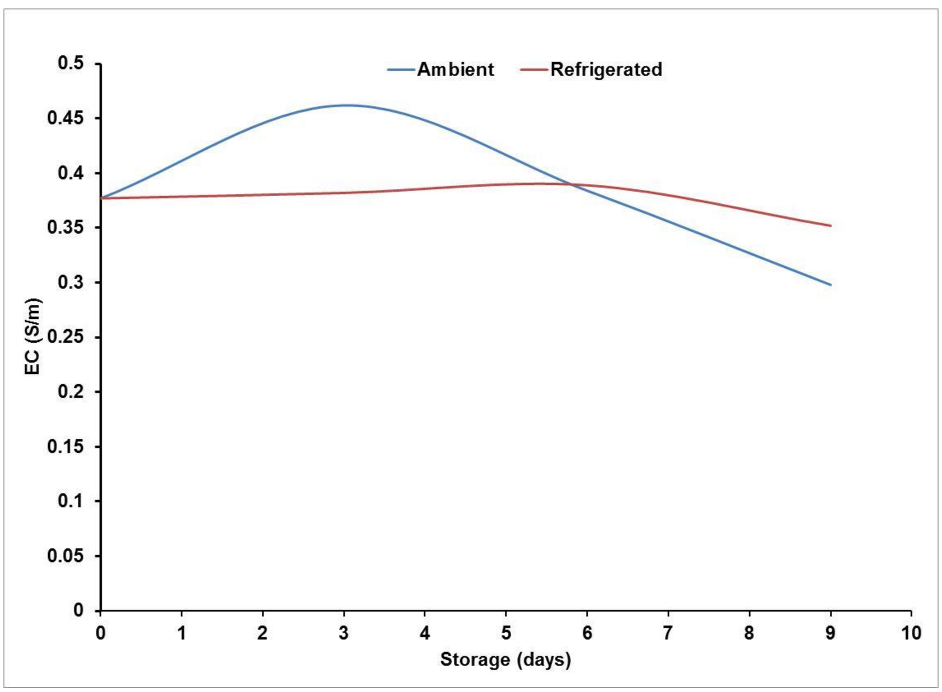

Figure 5. The pods' EC results.

processes (Ayman *et al*., 2012). Additionally, high temperature causes significant alterations to the cellular pattern of agricultural materials, which will subsequently affect their mechanical and electrical properties (Mthiyane *et al*., 2024).

Effect of storage conditions on the electrical properties

The results of okra pods EC and electrical resistivity (ρ) values are presented in Figures 5 and 6, respectively. This

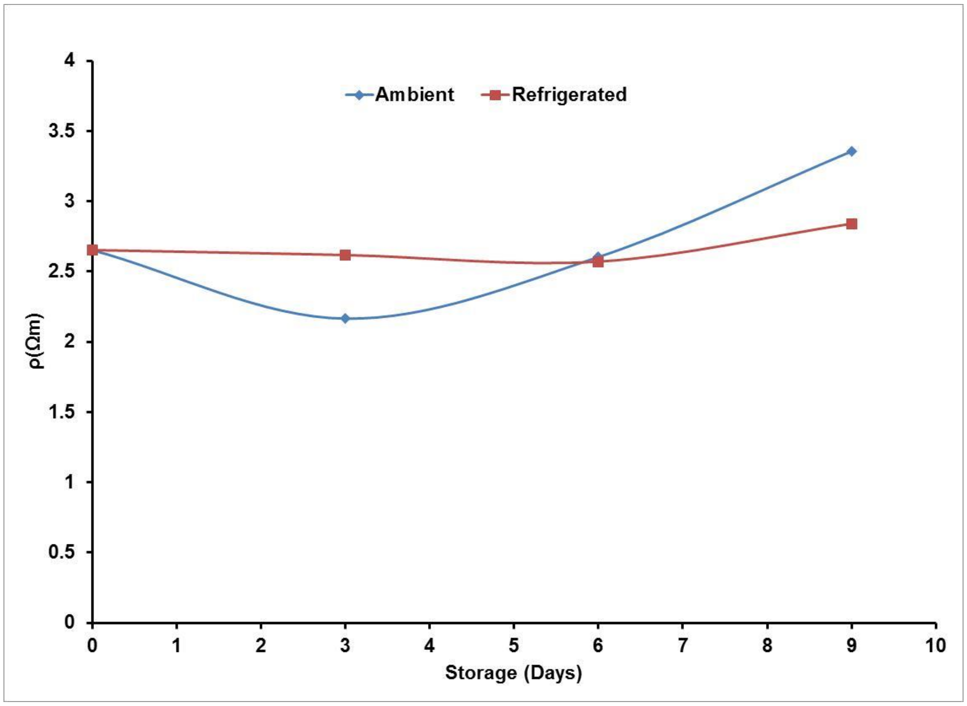

Figure 6. The pods ρ results.

research's outcomes highlighted that at the end of the experiment, the EC declined unevenly from 0.377 to 0.298 S/m in the ambient situation and from 0.377 to 0.352 S/m in the refrigerated storage condition. Similarly, the ρ values inclined non-linearly from 2.653 to 3.356 Ωm in the pods placed under the ambient condition, and from 2.653 to 2.841 Ωm for the batch kept at the cool (refrigerated) environment. The higher EC values obtained in the okra stored in the cooler condition could be attributed to the higher moisture level they contain. This elevated water level will facilitate dissolved ions and electrons mobility, hence, resulting in a greater electrical conductivity level within the pod juice (Banti, 2020). Interestingly, it was noted from the findings that, during the first three days, there was a slight increment in the electrical conductivity value; this boost can be attributed to ion concentration created within the okra pod, which can be attributed to mineral accumulation in the pod (Najafi *et al.,* 2024).

Engineering implications of the results

Notably, the compressive strength properties of the okra pod are essential for the design of appropriate storage and packaging systems for the okra pod after harvest. When compared to the valves acquired at the end of storage (180.86 N) under ambient storage conditions, the pod during harvest day had the lowest failure force, with a mean value of 62 N. If an automated system designer considered 0.22 N (the mean value of the pod used in this experiment at ambient), it can be observed that a heap of about 280 pods would be sufficient to cause the failure of the pod in the lowermost layer. Therefore, during storage of the okra pod, the packaging structure must be evaluated to withstand the maximum load. This will prevent irreversible damage related to impact during transportation. Also, the data obtained from this study will help to evaluate the integrity of the okra pod and its utilisation in electrical accessories.

Conclusions

This research was conducted to identify the impact of storage conditions on the electrical and strength parameters of okra pods. The findings from this research revealed that the electrical and compressive strength parameters have a strong relationship with storage duration for both storage conditions. Length decreased from 73.58 to 68.97 mm (6.26% decreased), and 74.96 to 72.93 mm (2.7% decreased) at ambient and refrigerated conditions, respectively, while the pod diameter value declined from 25.21 to 20.42 mm (19.00% decreased),

The failure forces, failure energy, rupture force and rupture energy increased significantly during storage, regardless of the storage conditions. The outcomes depicted that the increment was relatively more rapid under ambient conditions compared to the refrigerated storage conditions. Additionally, the electrical conductivity tends to decline during storage, while the electrical resistivity tends to increase during storage, regardless of the storage conditions. Interestingly, the information provided by this investigation can be useful for the design of smart okra pod packaging and integrity monitoring systems.

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

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