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Research article

Preservation and post-harvest quality of okra using low density polyethylene

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Abstract: Okra (*Abelmoschus esculentus* L. Moench) is a vegetable crop of high nutritional value, which presents great losses after harvest when stored under poor storage conditions. The objective of this research was to evaluate the effect of different low-density polyethylene (LDPE) thicknesses on the preservation and post-harvest quality of okra fruits under different storage periods. The experiment was conducted in a completely randomized design, with nine replicates, in a 5 × 5 factorial scheme, corresponding to five forms of packaging at a temperature of 10 ± 1 ℃: no film and four LDPE thicknesses (10, 20, 30, and 40 μm) with five storage periods (0, 7, 14, 21, and 28 days). It was revealed that the use of LDPE plastic films provided lower loss of mass, higher fruit firmness containment of increase in soluble solids, and lower color change at 21 days of storage compared to no film. The LDPE thickness of 30 μm showed lower incidence of rotting, better appearance throughout storage, lower color changes, containment of increase in soluble solids content, higher chlorophyll, ascorbic acid, and total phenolic content compared to other forms of packaging, and is the most appropriate package for storing okra fruits up to 21 days, under refrigeration condition. The results of this study show that the thickness of LDPE has significant effects on the conservation and quality of okra. Our findings can be used to minimize post-harvest losses of okra during marketing.

Keywords: *Abelmoschus esculentus*; plastic film; quality; modified atmosphere

1. Introduction

Okra (*Abelmoschus esculentus* L. Moench) is a traditional vegetable belonging to the Malvaceae family [1]. In several countries of the world, it is considered a basic food of great socioeconomic and nutritional importance for populations [2]. Okra fruits and seeds are edible; the immature fruits present medicinal, therapeutic, and nutritional properties and offers human nutrition dietary fiber, carbohydrates, B vitamins, calcium, iron, mineral salts, and antioxidant substances [3].

Among the relevant aspects of okra cultivation, its post-harvest management stands out as one of the main ones. After harvesting, vegetables become quite perishable owing to their high water content (90%) and intense metabolism that is characterized by high respiratory rate [4]. These factors, which are the biggest problem in the storage of okra, make okra fruit to have an extremely short storage period, mainly in poor storage conditions such as high temperature and low relative humidity, because these conditions accelerate the loss of water and darkening of fruits, thus, depreciating its commercial value for consumption in natura [4].

Normally, okra fruit is commercialized in natura in fairs, free markets, or supermarkets, and stored without temperature or humidity control, enabling the occurrence of wilting and water loss and depreciating the commercial value of the fruit [5]. Faced with this problem, different techniques are being used to increase the shelf life of fruits and vegetables; among them are the increase in air relative humidity, decrease in temperature, and modified atmosphere through the use of packaging or plastic films [6].

The use of plastic packaging or films is an alternative that increases the preservation of products by modifying their atmosphere, reducing their oxygen content and increasing their carbonic gas content, thus, delaying the senescence and prolonging the useful life of vegetables. Low density polyethylene (LDPE) is among the plastic films used in food storage [7].

Owing to the increased demand for fresh vegetables, it is necessary to research on storage alternatives to maintain the quality and freshness of vegetable products. In order to extend the shelf-life of okra, it is essential to package it in appropriate plastic films to reduce breathing. Besides, information on okra quality and post-harvest storage time is inadequate. The aim of this study was to evaluate the effect of different LDPE thicknesses on the preservation and post-harvest quality of okra fruits under different storage periods.

2. Materials and methods

2.1. Experimental area

The experiment was conducted from December 2017 to July 2018, at the Horticulture Laboratory of the Federal University of Technology—Paran á (UTFPR), Campus Dois Vizinhos, in the region of southwest Paraná (latitude of 25°42′S, longitude of 53°06′W, and average altitude of 520 m). The climate of this region, according to Koppen's classification, belongs to the Cfa—humid subtropical with hot summer [8].

2.2. Experimental design

The experiment was conducted in a completely randomized design, with 9 replicates, arranged

in a 5 × 5 factorial scheme, that is, five forms of packaging: no film (control) and four LDPE thicknesses (10, 20, 30, and 40 μm) with five storage periods (0, 7, 14, 21, and 28 days). Each experimental unit was composed of an expanded polystyrene tray with four okra fruits.

The okra fruits 'Speedy' were harvested when they were tender and at the commercial point of harvest, that is, approximately 70 days after sowing. Immediately after harvest, the fruits were packed in plastic packages previously sanitized and transported to the UTFPR Horticulture Laboratory. In the laboratory, the fruits were disinfected and immersed for 10 min in water containing 10 mL L^{-1} of sodium hypochlorite. Thereafter, the water was drained, and the okra washed in running water and then dried with paper towels.

Okra was selected according to its pattern of ripeness and color; those with any damage were discarded. The fruits were then packed in expanded polystyrene trays with LDPE films of different thicknesses (10, 20, 30, and 40 μm) and in trays without film (control).

In the sequence, each experimental unit was stored in a Biochemical Oxygen Demand (B.O.D) chamber with a temperature of 10 ± 1 °C and 90% relative humidity (RH). The values of temperature and relative humidity used during storage represent the optimal conditions recommended for okra storage [9].

Nine repetitions were used per treatment, and four of them remained closed until the end of the experiment; they were used for the analysis of weight loss and visual appearance. For color analysis, soluble solids, ascorbic acid, chlorophyll content, content of total phenols, and pH, the remaining five replicates were used; one replicate was analyzed each day of evaluation and discarded after the analysis. After the application of treatments, the fruits were evaluated every 7 days of storage.

2.3. Variables analyzed

2.3.1. Weight loss

Weight loss of fresh fruits was calculated from the differences in weight between the start of the experiment and each storage period, according to Equation 1. The fruits were weighed on a scale of precision.

$$\%\,Weight\,loss = \frac{(Inicital\,weight - final\,weight)}{Initial\,weight} x100 \quad (1)$$

2.3.2. Visual aspect

For visual aspect, the appearance of discoloration spots and incidence of rotting in each fruit of the experimental unit were evaluated; the presence of soft rotting fruits or pathogens (visible mycelium) was observed during the storage period. The evaluation of the presence of discoloration stains was performed according to the methodology described by Mota et al. (2006) [4], where subjective scores were used: (0) absence of dark spots; (1) absence of dark spots, slightly darkened; (2) small or slightly darkened spots, moderately darkened; (3) large and extremely darkened spots; and (4) spots distributed throughout the fruit and completely darkened, when the dark spots occupied more than 50% of the fruit surface.

2.3.3. Luminosity, coordinates a, and coordinates b

Color analysis of the epidermis was done with a Konica Minolta colorimeter (CR-400 model) with direct reading of L coordinates (luminosity/luminance), chromatic coordinate a (+ and/or −), chromatic coordinate b (+ and/or −), and Hue angel ($h = 180 + \tan^{-1}(b/a)$ performed in the central region of the fruit, and three color measurements on the surface of the fruit. For each treatment, 4 fruits were analyzed per evaluation day.

2.3.4. Total chlorophyll content

Total chlorophyll content was determined by the homogenization of 3 g of the median part of fresh fruits with 10 mg of magnesium sulphate and 30 mL of 80% (v/v) acetone. The resultant suspension was filtered and measured in a 50 mL volumetric flask. Total chlorophyll content was determined spectrophotometrically at wavelengths of 645 and 663 nm according to the methodology of Arnon (1949) [10].

2.3.5. Ascorbic acid

Ascorbic acid was determined according to the methodology described by the Adolfo Lutz Institute (2008) [11]. Samples of 5 g of fresh fruit were blended with 100 mL of distilled water using a food blender. Then, 20 mL of sulfuric acid (20%) was added to the mixture, and the solution was filtered. One milliliter of 10% potassium iodide and 5 mL of 1% starch solution were added to the filtrate. Subsequently, titration with 0.01 N potassium iodate solution was performed until the color of the solution turned blue [4].

2.3.6. Soluble solids and pH

Soluble solid contents (SS) were obtained using Hanna digital refractometer model H196801; the values were expressed in ºBrix (corrected for the temperature of 20 °C). For the SS reading, homogenized pulp was used. The pulp was obtained from four whole okra fruits (without seeds), which were homogenized with the aid of a blender. The mixture was then inserted in the calibrated refractometer with distilled water to obtain the ºBrix. For each treatment, four fruits were analyzed per evaluation day. The pH of homogenized fruit pulp was determined directly using Hanna® brand peagameter.

2.3.7. Fruit firmness

Fruit firmness was determined in the middle of the fruit using a manual penetrometer Instruterm PTR-100 with a 5 mm diameter tip. For each treatment, 6 fruits were analyzed per evaluation day.

2.3.8. Content of total phenols

The total phenolic content was determined using gallic acid as a standard for the calibration curve based on the procedures described by Singleton et al., (1999) [12]. 1.0 g of crushed sample

was weighed in centrifuge tubes and 9 mL of distilled water was added. After centrifugation for 30 minutes at 9520 x g, a 0.5 mL aliquot of the supernatant was transferred to test tubes, and 2.5 mL of 10% Folin-Ciocalteau reagent (v:v) was also added. After stirring, it was waited for 5 minutes and 2.0 mL of 4% sodium carbonate (v:v) was added. After stirring, it was waited for 5 minutes and 2.0 mL of 4% sodium carbonate (v:v) was added. After two hours in the dark, at room temperature, the absorbance of the samples was read at a wavelength of 725 nm using the UV-visible spectrophotometer (HITACHI, U-1100, Japan). The phenolic content was calculated using a standard curve with gallic acid.

2.4. Statistical analysis

Data obtained were homogenized and normalized using the Bartlett test and analyzed using analysis of variance (ANOVA), F test, and regression of the statistical program SAS Studio [13]. The means of qualitative variables were compared using the Tukey's and Scot Knot's tests at 5% probability. For quantitative factors, models were chosen based on the significance of coefficients at 5% probability. For variables regarding visual aspect analysis of discoloration stains, results were subjected to square root transformation before performing analysis of variance.

3. Results and discussion

3.1. Weight loss

It was observed that okra fruits packed in LDPE packages differed statistically from those in the control (without film), resulting in a lower percentage of fresh weight loss during the storage period (Figure 1A). The smallest weight loss was observed in the LDPE thickness of 40 μm, with 4.2% (7 days); 4.1% (14 days); 3.1% (21 days), and 2.0% (28 days). The efficiency of LDPE packaging in controlling weight loss is justified by the formation of a microenvironment saturated with moisture inside the package, resulting from a low water vapor transmission rate [14], demonstrating the potential of LDPE package in the storage of okra fruits. Similarly, [15] found the lowest weight loss (3.9%) in okra fruits packaged in LDPE compared to fruits stored in bowls at room temperature.

For fruits stored without film, the percentages weight losses were the highest, with 36.1% (7 days), 56.4% (14 days), 74.9% (21 days), and 81.3% (28 days). We observed that an increase in weight loss until the end of the experiment, with an increase of 45% weight loss as from 7 to 28 days of storage. Weight loss in fruits stored without film (control) resulted from a great difference between the internal water vapor pressure of fruits and its surrounding atmosphere and the loss of reserve in fruits tissues owing to biochemical activities such as increased respiration and transpiration processes [16].

[17] also reported significant loss of weight (21.16%) in okra fruits stored without film at a temperature of 9 ± 1 °C and 90 ± 5% RH) at 4 days of storage. The high losses of fruit weight resulted from the loss of okra water to the atmosphere during the storage period, because the water vapor pressure of the fruits was higher than the water vapor pressure of the chamber air, resulting in a water vapor deficit of okra; water vapor migrated from a higher pressure to a lower pressure, causing the loss of product weight [18].

Okra fruits packed in LDPE plastic film resulted in lower weight loss compared to those in control (without film), owing to modified atmosphere, which regulates the storage conditions required to maintain the quality of fresh fruits for a long period under controlled temperature [16].

3.2. Visual aspect

For visual appearance analysis, we observed the development of stains and discoloration of fruits in all samples as storage time increased (Figure 1B).The fruit without film (control) differed statistically from the fruit packed in LDPE at 7 days of evaluation; a higher score on the visual scale, equal to 1 (slightly darkened), was obtained. This higher incidence of discoloration stains on the filmless fruits may be caused by 'chilling', owing to the exposure time of okra without coating at low temperatures (10 ± 1 °C).

At 14 days of evaluation, we found that there was no significant difference between the control samples and the 10 and 30 μm thick LDPE. However, it was observed that the LDPE thicknesses did not differ, presenting the best results for visual appearance (Figure 1B). During this period, the fruits of the control sample (without film) were already shriveled and wrinkled owing to accentuated dehydration and were not suitable for commercialization.

At 21 days, the appearance of fruits stored with LDPE thicknesses of 30 and 40 μm differed significantly from those stored with other packages, suggesting that the fruits until 21 days of storage presented good appearance for commercialization, with scores equal to 2 (Figure 1B). During this period, the okra fruits with LDPE thicknesses of 10 and 20 μm, obtained the lowest scores (dark scores), owing to the pronounced presence of rotting in them.

On the 28th day of storage, the fruit packed in LDPE 30 and 40 μm thick showed better appearance, expressing scores between 2 and 3 on the visual scale. Although it did not differ statistically, the 40 μm thick LDPE was better in preserving the visual aspect of the fruit during storage. These results corroborate that of [15] who reported the positive effects of LDPE on okra stored under refrigeration. According [19], the packaging of vegetables such as paprika and okra in low-density polyethylene films reduces the appearance of symptoms caused by cold, during storage.

Regarding rotting, no rotting or visible mycelium was observed in any fruit samples stored up to 14 days. From the 21st day upward, rotting and visible mycelium were observed in the fruits of control treatment (without film) and LDPE of 10 and 20 μm thickness; however, fruits in control treatments showed a higher incidence of rotting compared to those in other LDPE thicknesses.

At the end of the evaluation period, at 28 days, all samples had an incidence of rotting and visible mycelium in their fruits, except LDPE of 30 μm. For the fruits packed in LDPE of 10 and 20 μm, the accentuated incidence of rotting was associated with high humidity inside the package, which favored the growth of fungi [20], and was also owed to the thickness of the film, which did not alter the gaseous composition adequately, that is, it did not allow the reduction of oxygen levels and the accumulation of high concentrations of carbon dioxide [21], which could reduce fruit rotting.

Among the different LDPE thicknesses, the 30 μm was the one that allowed significant reduction of fruit rotting up to 28 days of storage, by causing the accumulation of more carbon dioxide inside the package, reducing fruit respiration [16]. [21] also observed excellent appearance in broccoli packaged in LDPE of 30 μm at 5 ± 1 °C and 90% ± 5% RH until the 11th day of storage; however, incidence of rotting in the fruits after 18 days was reported.

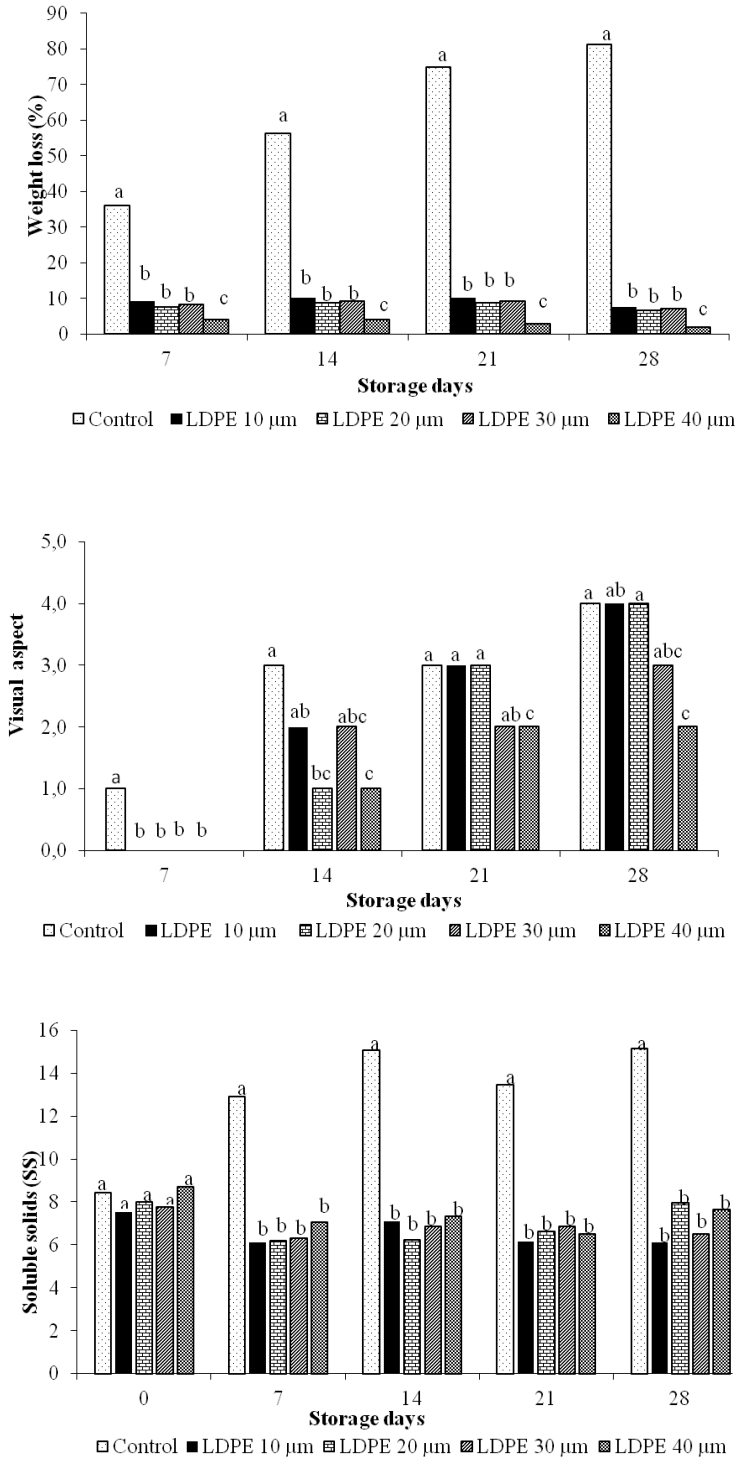

Figure 1. Weight loss (1A), Visual aspect (1B), and Soluble solids (1C) of okra fruits stored in different LDPE thicknesses (10, 20, 30, and 40 µm) and control (without film).

3.3. Soluble solids

The contents of soluble solids in fruits packed in LDPE of 10, 20, 30 and 40 µm during the

storage period were lower compared to those in the control (without film) (Figure 1C), probably owing to the permeability of LDPE to water vapor, which reduced water loss in the fruits, avoiding the concentration of pulp and reduction of respiratory metabolism in fruits by decreasing oxygen and increasing carbon dioxide inside the packages [16].

However, the levels of soluble solids in the fruit stored without film (control) showed gradual increase from the 7th day of storage starting at 8.41 °Brix and extended to the end of the experiment (28 days), with an average level of 15.1 °Brix (Figure 1C). An increase in soluble solids in fruit samples increases the ripening processes of fruits [22]. During ripening, soluble solid contents increased owing to the transformation of insoluble polysaccharides into soluble sugars [9]. The elevation of the soluble solids can also be associated to a greater loss of water by the fruits, since loss of water results in the concentration of pulp, increasing the soluble solids [23].

The differences in soluble solid contents observed between fruits stored without film (control) and those stored with LDPE is owed to the modified atmosphere that inhibits respiratory processes, causing delay in the advancement of fruit ripening [24] and consequently in the consumption of soluble solids, the main substrates of respiration [25].

3.4. pH

The pH of okra fruits had no interaction between LDPE thicknesses and days of storage. However, pH at days of storage was significantly different between treatments; the fruits packed in LDPE of 20 μm had higher pH value than those in other packages (Table 1). At 14 days, pH did not differ between treatments. At the end of the evaluation period (28 days), the fruits packaged with LDPE of 10 μm presented the highest pH value. The lowest pH value was obtained in fruits stored without film (control), indicating a degradation of chlorophyll at low pH.

The pH of fruits stored with different LDPE thicknesses ranged from 6.4 to 6.7, indicating the maintenance of fruit ripening.

Table 1. pH results of okra fruits stored in different LDPE thicknesses (10, 20, 30, and 40 μm) and control (without film).

	Storage days				
LDPE (microns)	0 day	7 days	14 days	21 days	28 days
Control	6.9 a*	6.6 ab	6.7 ns**	6.4 b	5.5 c
10	6.5 b	6.5 b	6.7	6.7 a	6.7 a
20	6.4 b	6.7 a	6.7	6.7 a	6.5 b
30	6.6 b	6.6 ab	6.7	6.6 a	6.5 b
40	6.4 b	6.5 b	6.7	6.7 a	6.4 b
Mean	6.56	6.58	6.70	6.60	6.32
C.V. (%)	1.37	0.72	0.62	1.79	2.33

Note: *Means followed by the same letter in the column do not differ statistically by Scot Knot's test ($P < 0.05$); **^{ns} not significant.

3.5. Luminosity, coordinates a, coordinates b and Hue angle

In all treatments, okra presented average values of between 51.9 and 37.8 for luminosity (L),

suggesting a relatively dark coloration, since the closer the L gets to 100, the lighter the color tone, and the closer the L gets to zero, the darker the fruit shade [19]. There was no significant difference in luminosity factor between treatments until the 14th day of storage (Table 2).

At 21 days of evaluation, okra under the control treatment had lower mean L and differed statistically from those under LDPE treatments, indicating darkening of fruits (Table 2). Although the samples had variations in their values, it is possible to observe a reduction in luminosity during storage, which is an indication that there was darkening of fruits. The results are in accordance with that of [15].

At 28 days of evaluation, the fruits without film (control) and LDPE of 10 and 20 μm obtained lower average luminosity than those stored with LDPEs of 30 and 40 μm, indicating darker shades in the fruits.

The chromatic coordinate values of the fruits were between −16.8 and −6.6, revealing green coloration. The values of coordinate b, which varies from blue (−b) or yellow (+b), were between +32.1 and +21.4, corresponding to a slightly yellow coloration (Table 2). There was no significant difference between the samples for chromatic coordinate a. However, during storage period, there was an increase in chromatic coordinate a for all treatments, indicating loss of green coloration. The increase in the chromatic coordinate a was in this order: −17.0 to −11.5 for the control, −16.7 to −6.6 for LDPE of 10 μm, −16.4 to −9.6 for LDPE of 20 μm, −16.6 to −14.4 for LDPE of 30 μm, and −16.5 to −15.8 for LDPE of 40 μm . The results are in accordance with that of [26] who reported an increase in the value of chromatic coordinate a to be in the range of −15.6 to −9.8 for okra fruits under 9 days of refrigeration storage.

For chromatic coordinate b, there was a reduction of b in the fruits as the days increased: +27.4 to +23.1 for LDPE of 10 μm, and +28.8 to +23.3 for LDPE of 20 μm. This reduction indicates a decrease in the intensity of the yellow color of the fruits. At this coordinate, there was a significant difference at 21 days of storage, in which the LDPE of 30 μm, with the highest result of chromatic coordinate b (32), differed statistically from other LDPE thicknesses.

When evaluating the variable hue color angle we found that LDPE treatments better maintained the characteristic color of the fruits for 28 days (Table 2). Fruits stored without film (control) showed a significant reduction in color, the color angle values (hue) decreased 8.62%, at 28 days of storage.

Compared to control, LDPE thicknesses of 30 and 40 μm expressed the best results for luminosity, chromatic coordinates a and b, and Hue angle as they were at a less pronounced stage of maturation, at 28 days of storage.

3.6. Fruit firmness

Fruit firmness was retained with the application of LDPE using thicknesses of 30 and 40 μm; the reduction in fruit firmness was 3.38 and 3.00%, respectively, whereas that in the fruits without film (control) was 5.07% (Table 3). The decrease in fruit firmness was related to the loss of mass; the fruits stored without film (control) presented a higher loss of mass and lower firmness than fruits with films. Firmness is an indicator of freshness and determines the quality of okra, because loss of firmness is evaluated as a sign of senescence. During post-harvest storage, any environmental or physiological factor that adversely affects cellular components can lead to deterioration or loss of firmness, resulting in undesirable changes in the quality of fresh fruits [27].

The restriction on metabolic activities under modified atmospheric storage is associated with

reduced activity of cell wall-degrading enzymes in okra fruits, which subsequently results in retention of firmness for longer durations [28]. The decrease in fruit firmness is associated with cell wall degradation through increased enzymatic activity (pectinases) associated with other processes, such as starch hydrolysis. Pectins contribute to mechanical resistance of cell wall and the adhesion between cells and any modification in their characteristics results in changes in fruit texture [29].

Table 2. Coloring of okra stored in different LDPE thicknesses (10, 20, 30, and 40 μm) and control (without film) for 28 days.

Storage days								
	0 day				7 days			
LDPE (microns)	L	a	b	Hue angle	L	a	b	Hue angle
Control	47.2 ^{ns}*	−17.0 ^{ns}	26.9 ^{ns}	122.17^{ns}	43.5 ^{ns}	−13.9 ^{ns}	24.5 ^{ns}	119.61^{ns}
10	48.9	−16.7	27.4	121.37	47.0	−16.8	30.5	118.92
20	51.9	−16.4	28.8	120.75	43.2	−15.7	27.9	119.33
30	48.7	−16.6	26.6	122.00	46.1	−16.1	29.7	118.52
40	50.2	−16.5	28.9	119.75	47.9	−16.4	30.6	118.14
Mean	48.5	−16.6	27.7	121.21	45.8	−15.9	28.5	118.90
C.V. (%)	7.68	4.81	10.2	6.54	10.08	11.76	12.42	5.26
	14 days				21 days			
LDPE (microns)	L	a	b	Hue angle	L	A	b	Hue angle
Control	43.7 ^{ns}	−12.4 ^{ns}	25.4 ^{ns}	116.12 ^{ns}	39.4 b	−9.5 ^{ns}	26.5 ab	109.72 b
10	47.1	−15.3	29.5	117.39	51.1 a	−13.9	29.5 ab	115.25 a
20	45.2	−12.9	25.6	116.68	49.4 a	−13.1	28.5 ab	114.54 a
30	48.9	−15.9	30.1	117.88	53.0 a	−15.6	32.0 a	116.00 a
40	49.2	−16.3	29.9	118.65	48.1 a	−14.1	28.7 ab	116.12 a
Mean	47.7	−14.9	28.7	117.34	48.1	−12.5	27.8	114.33
C.V. (%)	10.64	18.07	13.62	6.23	7.94	29.8	17.05	9.45
	28 days							
LDPE (microns)	L	a	b	Hue angle				
Control	42.0 ^{ns}	−11.5 ^{ns}	28.9 ^{ns}	111.64 c*				
10	37.8	−6.6	23.1	114.54 ab				
20	45.0	−9.0	23.3	118.14 a				
30	48.0	−14.4	27.9	117.27 a				
40	48.0	−15.8	30.0	117.76 a				
Mean	45.00	−12.1	26.2	115.87				
C.V. (%)	16.06	20.01	19.01	8.72				

Note: L*—Luminosity; a—Chromatic Coordinate a; b—Chromatic Coordinate b; ^{ns}—not significant; *Means followed by the same letter in the column do not differ statistically by Tukey's test ($P < 0.05$).

The acceptance of okra fruits by consumers depends on numerous factors such as appearance,

texture, taste, and nutritional value. Vegetables that maintain firmness and turgidity are highly desirable because they are associated with the freshness of the vegetable in natura [30]. LDPE thicknesses of 30 and 40 μm yielded the best results for fruit firmness compared with the fruits stored without film (control) during storage periods.

Table 3. Fruit firmness of okra fruits stored in different LDPE thicknesses (10, 20, 30, and 40 μm) and control (without film).

	Firmness (kg)				
LDPE (microns)	0 day	7 days	14 days	21 days	28 days
Control	5.32	5.23 c*	5.17 c	5.12 c	5.05 c
10	5.32	5.25 b	5.21 b	5.15 b	5.09 b
20	5.32	5.27 ab	5.23 b	5.17 b	5.11 b
30	5.32	5.29 a	5.26 a	5.20 a	5.14 a
40	5.32	5.30 a	5.28 a	5.21 a	5.16 a
Mean	5.32	5.27	5.23	5.17	5.11
C.V. (%)	-	4.32	5.15	5.01	4.87

Note: * Means followed by the same letter in the column do not differ statistically by Scot Knot's test ($P < 0.05$).

3.7. Chlorophyll content

The chlorophyll content of fruits was significantly different between the LDPE thicknesses and control (Table 4). The 30 and 40 μm LDPE had the highest chlorophyll contents; they were better in retaining the color of fruits, whereas the fruits stored without film (control) had lower chlorophyll content, presenting the highest color loss. The degradation of chlorophyll in non-climatic vegetables, such as okra, can be a disadvantage in quality, because chlorophyll is a reflection of senescence [4]. Moreover, a decrease in chlorophyll during storage is expected owing to the degradation of chlorophyll by chlorophyllase enzyme [31] and recent identification of an urobilinogenoidic Chl catabolite UCC as the sole degradation product of Chl in maple and of persistent termed hypermodified (hFCCs) were recently identified and showed to increase with the progression of senescence [32]. Similar results were reported by Singh et al. (2020) [16].

Table 4. Chlorophyll content of okra fruits stored in different LDPE thicknesses (10, 20, 30, and 40 μm) and control (without film).

	Total chlorophyll content (mg 100 g^{-1} fresch mass)				
LDPE (microns)	0 day	7 days	14 days	21 days	28 days
Control	1.264 c*	0.952 c	0.893 c	0.663 c	0.454 c
10	1.457 b	1.253 b	1.192 b	1.113 b	0.981 b
20	1.794 b	1.562 b	1.318 b	1.204 b	1.151 b
30	1.942 a	1.805a	1.719 a	1.542 a	1.471 a
40	2.225 a	2.125 a	1.921 a	1.432 a	1.422 a
Mean	1.736	1.539	1.409	1.191	1.096
C.V. (%)	12.31	10.42	7.35	14.47	15.32

Note: * Means followed by the same letter in the column do not differ statistically by Scot Knot's test ($P < 0.05$).

The maintenance of fruit color is important because it is an important characteristic in all phases of production, such as storage and marketing. Chlorophyll is a pigment that affects the quality of vegetables owing to modified atmosphere [18]. The smallest alteration in the color of fruits stored with LDPE is due to a modification in the atmosphere.

3.8. Ascorbic acid

The initial ascorbic acid content of okra fruits was 12.0 mg 100 g^{-1}. It was observed that okra fruits stored with LDPE of 30 and 40 µm had high levels of ascorbic acid during storage period (Table 5). These results are in accordance with that of [15]. However, the lowest ascorbic acid content (6.54 mg 100 g^{-1}) of okra fruits was observed in the control (without film) at 28 days of storage.

The ascorbic acid of okra fruits packed in LDPE during storage tended to decrease. The lowest losses of ascorbic acid in okra fruits packed in LDPE of 30 and 40 µm after 28 days of storage were 2.36 and 2.28 mg 100 g^{-1}, respectively. However, the greatest losses were observed in control (5.46 mg 100 g^{-1}). This reduction in ascorbic acid content with increasing storage period was also reported by Mota et al. (2006) [4].

The decrease in ascorbic acid during storage may be due to oxidation of L- ascorbic acid into dehydroascorbic acid [24]. Moreover, ascorbic acid is generally degraded by oxidative processes that are stimulated by light, oxygen, peroxides, and ascorbate oxidase or peroxidase [33].

Table 5. Ascorbic acid of okra fruits stored in different LDPE thicknesses (10, 20, 30, and 40 µm) and control (without film).

	Ascorbic acid (mg $100g^{-1}$)		
LDPE (microns)	0 day	14 days	28 days
Control	12.00	8.20 c*	6.54 c
10	12.00	9.27 b	8.66 b
20	12.00	9.40 b	8.85 b
30	12.00	10.37 a	9.72 a
40	12.00	10.32 a	9.64 a
Mean	12.00	9.51	8.68
C.V. (%)	-	5.85	7.32

Note: * Means followed by the same letter in the column do not differ statistically by Scot Knot's test ($P < 0.05$)

The nutritional quality, in terms of ascorbic acid, of okra fruits with high nutritional value can be retained for 28 days when packaged with LDPE of 30 and 40 µm. This may be due to low O_2 availability and consequent increase in CO_2 level owing to reduced respiration [16]. According to [34] ascorbic acid is one of the most important antioxidants that eliminates harmful free radicals and chelates heavy metals.

3.9. Content of total phenols

The total phenolic content of Okra fruits stored in LDPE of 30 and 40 µm was significantly ($P < 0.05$) higher than that of fruits without film; however, the control fruits (without film) had the lowest content (101.27 mg gallic acid/100 g) at 28 days of storage (Table 6).

The total phenols of okra fruits packed in LDPE during storage tended to decrease. The lowest total phenolic losses in okra fruits packed in LDPE of 30 and 40 μm after 28 days of storage were 9.67% and 11.19%, respectively. However, the greatest losses were observed in the control (25.37%).

The total phenolic losses during storage in the okra fruits may be attributable to its metabolic conversion to secondary phenolic compounds or degradation by enzymatic action [35].

According to [36], bioactive compounds, such as phenolic compounds, have become a topic of interest in research due to the countless characteristics that are beneficial to human health (e.g., their part in reducing the incidence of degenerative diseases, such as cancer and diabetes). They also have antioxidant, antimutagenic, antiallergic, anti-inflammatory, and antimicrobial effects [36].

Table 6. Total phenols of okra fruits stored in different LDPE thicknesses (10, 20, 30, and 40 μm) and control (without film).

	Total phenols (mg gallic acid/100 g)		
LDPE (microns)	0 day	14 days	28 days
Control	135.70	111.15 c*	101.27 c
10	135.70	118.25 b	110.25 b
20	135.70	124.42 ab	114.42 b
30	135.70	131.51 a	122.58 a
40	135.70	128.34 a	120.51 a
Mean	135.70	122.73	113.81
C.V. (%)	-	8.85	9.32

Note: * Means followed by the same letter in the column do not differ statistically by Scot Knot's test ($P < 0.05$)

Total phenolic compounds are secondary metabolites with a wide spectrum of biochemical activities. They have been reported to have antioxidant activity, which allows them to scavenge active oxygen species and electrophiles and chelate metal ions. These compounds have the potential for auto-oxidation and the ability to modulate certain cellular enzymatic activities [36,37].

[38] evaluated the antioxidant activity and phenolic content of nineteen vegetables commonly consumed in India and okra fruits had the highest levels of phenolic content (167.70 mg gallic acid/100 g), being ranked third behind purple cabbage and broad beans.

4. Conclusions

The quality and appearance of fruits stored with LDPE of 30 μm thickness are better preserved, with lower incidence of rotting, less color changes and containment of the increase in soluble solid content, higher ascorbic acid, total phenols, and chlorophyll contents being the most indicated for the storage of okra fruits under refrigeration condition of up to 21 days. This study contributes important information for the production of quality okra, with high nutritional value and great economic and social importance for family agriculture.

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Conflict of interest

All authors declare no conflicts of interest in this paper in this section.

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