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Effect of Gamma Irradiation on Different Starch Sources as Edible Coating on Preserving Lemon Fruit under Cold Storage Conditions

Fatma K.M.Shaaban[1], Amr M. Mounir* [2] and Yousra E. Hassan [2]

(1) Fruit Handling Research Department, Horticultural Research Institute, Agricultural Research Center, Giza, Egypt

(2) Natural Products Research Department, National Center for Radiation Research and Technology (NCRRT), Egyptian Atomic Energy Authority (EAEA), Cairo, Egypt

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ABSTRACT

This experiment was carried out during the two successive seasons of 2018/2019 and 2019/2020 to investigate the influence of un-irradiated and irradiated starch with gamma rays at 20 kGy of corn, sweet potato and cassava as an edible coating at 2% concentration on enhancing the storage ability and increasing the storage period of lemon fruits under cold storage conditions. Data revealed that lemon fruits coated with irradiated cassava starch scored the lowest weight loss percentage and respiration rate at the end of the storage period, whereas lemon fruits coated with both un-irradiated and irradiated cassava starch scored the highest general appearance of lemon fruits at the end of storage period .As for fruit colour, lemon fruits coated with irradiated cassava starch followed by irradiated sweet potato starch scored higher fruit lightness (L*) value and lower density of yellow colour (h°) value than un-coated fruits especially at the end of the storage period. As for the fruit chemical constituents, fruits coated with cassava starch had higher titratable acidity percentage, soluble solids content and ascorbic acid concentration than those handled by other treatments at the end of the storage period.

1. INTRODUCTION

Lemon (*Citrus limon*) is considered one of the most important crop of family Rutaceae, it has unrivalled flavor, acidity, a great amount of ascorbic acid and phenols as well as flavonoids. Although lemon is considered one of the non-climacteric fruit and produce low carbon dioxide and ethylene which led to a small physical and chemical changes during storage and transport [1] , the main problem during storage is water evaporation through peel skin which leads to the increase of weight loss through vital processes such as respiration and transpiration and undesirable changes of peel colour from green to yellow [2]. The excessive water loss through lemon fruit skin encourages the production of ethylene which is related to the stimulation of chlorophyllase enzyme that increases the breakdown of chlorophyll which converts the peel colour from green to yellow.

Using edible coating as a post-harvest treatment can delay fruit senescence, shrinkage from water evaporation and make a modified atmosphere around fruit skin. Different types of edible coatings were used in covering fruits, these coatings are composed from proteins, polyscaccharides and lipids [3]. These edible coatings are characterized by their safe usage and can be used as a thin layer around the fruit skin by different methods such as dipping, spraying and soaking which maintain fruits against water loss through evaporation and transpiration[4]. Starch based edible coating can be used as the optimum lower cost method, it is ecofriendly compared topackaging to preserve fruits during storage[5].

In the last ten years, starch became one of the most hopeful natural materials for the fabrication of biodegradable plastics [6]. Although it is characterized by its low cost and it is easy to obtain, it has some unfavorable characters when it is compared to traditional polymers. The main negative point is that it is submitted to deterioration process over time, which prohibits its practical utilization in industry. Some additives could ameliorate its characters such as glycerol [6] which plays the role of plasticizer that enhances the mechanical properties of the thin layer of edible coating, improving its deformability throw decreasing the glass transition temperature [7], and the flexibility of the edible coating. In addition it has the ability to affect water loss and gas

Corresponding author: mouniramr80@gmail.com
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exchange, whereas it is of very hydrophilic and hygroscopic nature[8].Glycerol is characterized by its low molecular weight, which increases the combination between the macromolecules, that improves the mobility of the polymer chains and decreases the glass transition temperature of the coating [9].

Regarding the total production of starch which reach approximately 60 million tons of starch extracted from several crops, maize or corn starch is still the most useful natural material in industry [10], and it is an important raw material to use in the composition of edible coating [11]. The main ingredient is amylose ,which is characterized by its ability to form a thin film around fruits and its compatibility with solvents and plasticizers to obtain the best physical and mechanical properties[12].Starch based edible coating show a superb role against water loss from skin and play an important role as an obstacle against oxygen loss under minimum moisture conditions [13].Several studies found that starch edible coating diminishes weight loss and increases the storage period of lemon [14].

Sweet potato starch is a considerable biopolymer which contains 58-76% starch (on a dry basis), for making pure and elastic coatings [15].Basically, raw sweet potato starch has a restricted utilization as a result of its insufficiency of clarity, and lack of viscosity as well as power of thickness [16].

Cassava starch is considered one of the promising starch sources used in edible coating due to its characters, such as being isotropic, scentless, savorless, safe in usage, non-toxic, biodegradable, flexible, considered as good barrier against water loss [17].

Gamma irradiation is used as a traditional method for adjustment of polymer compounds via liaison, grafting and disintegration mechanism . Moreover, it has the capability to produce free radicals which stimulate the molecular changes and shatter the degradation of starch or cross-link of starch chain depending on dose and conditions [18]. These changes lead to a modification of the structure, physical and chemical characters as well as digesting starch [19].Gamma irradiation has the ability to hydrolyze the chemical bonds of starch and convert it to sample chain, ameliorate the solubility, reduce the viscosity of starch which reflect on making it more useful in applications[20].

Thus the aim of the present study is to evaluate the impact of different un-irradiated and irradiated starch sources as an edible coating on enhancing the storage ability of lemon fruits under cold storage conditions.

2. MATERIALS AND METHODS

Lemon (*Citrus limon*) fruits were obtained, from a private orchard at El Nubaria, Behaira Governorate at the first week of December during the two successive seasons of 2018/2019 and 2019l2020. Mature fruits were harvested and immediately transported to the Fruit Handling Research Department, HRI,MOI.

Corn starch, sweet potato starch and cassava starch were exposed to 20 kGy of gamma irradiation (Indian cell ^{60}Co) at a dose rate of 1.029 KGy/h, at the National Center for Radiation Research and Technology (NCRRT), Atomic Energy Authority, Cairo, Egypt.

Sound fruits were selected on the basis of uniformity of size and color and then divided into seven treatments as follows:

1- Control (un-coated fruits).

2- Fruits coated with un-irradiated corn starch.

3- Fruits coated with irradiated corn starch.

4- Fruits coated with un-irradiated sweet potato starch.

5- Fruits coated with irradiated sweet potato starch.

6- Fruits coated with un-irradiated cassava starch.

7- Fruits coated with irradiated cassava starch.

All fruits were soaked for 2 minutes in solutions of different sources of starch at a concentration of 2% and glycerol (Merck) 87% was added as a plasticizer (2 ml/l) for all treatments.

Each treatment was represented in 3 replicates. All treatments were stored at 5°Cand 90% relative humidity (RH) in carton boxes. Changes in the physical and chemical properties of fruits were evaluated every two weeks from the beginning to the end of the storage period.

Physical properties:

Fruit weight loss Percentage (FWL %): The percentage of fruit weight loss was calculated according to the following equation:

$$FWL\% = [(Wi - Ws)/ Wi] x100$$

Where, Wi = fruit weight at the beginning of the experiment.

Ws = fruit weight at the examination date.

Respiration rate (CO_2 production):

Individual fruits from each treatment were weighed and placed in 2 liter jars at 20 ° C. The jars were sealed for 3 h. with a cap and a rubber septum. O2 and CO2 samples of the head space were taken by a syringe and injected directly into Service Inst. Model 1450 C (Food Pack Gas Analyzer) to measure its concentrations. Respiration rate was calculated as ml CO2 /kg/h. [21].

General appearance:

General appearance was measured by a rating system and fruit was scored as: very good = 9, good = 7, acceptable = 5, unacceptable=3, Poor = 1

Fruit color: Lightness (L*) and hue angle (h°) were estimated using Minolta Calorimeter (Minolta Co. Ltd.,Osaka, Japan) as described by Mc Gire [22].

Chemical Properties

Titratable acidity percentage:

Total acidity percentage was determined by titration according to A.O.A.C. [23]. It was expressed as (g citric acid/100ml juice).

Soluble solids content (SSC):

Soluble solids content were determined using a digital refractometer (Model Abbe Leica), according to A.O.A.C. [23].

Ascorbic acid concentration:

Ascorbic acid concentration was determined by titration against 2, 6 dichlorophenolendophenol, and calculated in milligram per 100 ml. of juice [24].

Statistical analysis.

This experiment was arranged in a completely randomized design (CRD), all data were subjected to statistical analysis according to the procedures reported by Snedecor and Cochran [25] and means were compared by Duncan's multiple range tests ($P \leq 0.05$) [26].

3. RESULTS AND DISCUSSION

3.1. Physical properties

3.1.1. Fruit weight loss Percentage

Data presented in Table (1) clearly indicated that weight loss percentage increased gradually and significantly with extending cold storage period with significant differences among them during the two successive seasons. This result was in the same line of Thapaa et al. [27] who confirmed that the advancement of storage period was accompanied by an increase in weight loss percentage of sweet orange fruits. The least value of the weight loss percentage (9.22 and 10.54%) was obtained by irradiated cassava starch followed by irradiated sweet potato starch (9.40 and10.86%) in the first and second seasons. On the other hand, un-coated fruits exhibited the highest value of weight loss percentage (12.77 and 13.16 %) in both seasons. Similar result was obtained by Solis Jimenez et al. [28] who found that avocado fruits coated with cassava starch edible coating scored lower weight loss percentage than the un-coated fruits and Oyom et al. [29] who found that early crisp pear coated with sweet potato starch incorporated with cumin essential oil scored the lowest weight loss percentage during storage.

As for the interaction, significant differences were detected in the interaction between the two studied factors (storage periods and treatments). At the end of storage period, the least value of weight loss percentage was obtained by fruits treated with irradiated cassava starch in both

seasons. However, the highest value of weight loss percentage was obtained by the un-coated fruits (control) during the two successive seasons.

3.1.2. Respiration rate (ml CO_2 /kg/h.)

Data presented in Table (2) indicated that respiration rate was increased gradually toward the end of storage period. This result is in the same line of Wan et al. [30] who found that although there was a decrease in respiration rate of navel orange at the beginning of the storage period, it was noticed that there was a gradual increase in the respiration rate till the end of storage period.

All treatments significantly decreased the respiration rate compared with the un-coated fruits during both seasons of the current study, whereas irradiated cassava starch scored the lowest respiration rate in both seasons. Similar finding was obtained by Oyom et al. [29] who found that early crisp pear coated with sweet potato starch enriched with cumin essential oil delays the respiration rate of fruits during the storage period and Shaaban and Hussein [31] who observed that cassava starch edible coating scored the lowest respiration rate of guava fruits during cold storage.

As for the interaction, at the end of storage period, fruits coated with irradiated cassava starch recorded the lowest value of the respiration rate in the two successive seasons. On the contrary, the highest value of the respiration rate was found in the un-coated fruits in the first and the second seasons.

The higher respiration rate detected in the un-coated fruits might be attributed to skin dryness preventing the exchange of gases [32] Additionally, there is a considerable relation between the weight loss and the production of carbon dioxide which is produced through the respiration process of fruits. Edible coating in this research play an important role in retarding senescence of lemon fruits by acting the role of packaging which modifies the atmosphere around the fruits and manages the production of CO_2 and decreases its production consequently reflecting on diminishing the weight loss percentage and the respiration rate of fruits[33].

Table (1): Effect of un-irradiated and irradiated corn, sweet potato and cassava starch edible coatings on weight loss percentage of lemon fruits stored at 5 ℃ and 90-95 %RH during 2018/2019 and 2019/2020 seasons

Treatments	Storage period per weeks					
	0	2	4	6	8	Mean
2018/2019						
Control	0.00 q	8.16 lm	15.81 f	17.87 c-e	22.03 a	**12.77 A**
un-irradiated corn starch	0.00 q	6.93 no	13.78 hi	17.56 de	21.63 ab	**11.98 B**
irradiated corn starch	0.00 q	7.55 mn	12.19 k	15.24 fg	21.42 ab	**11.28 C**
un-irradiated sweet potato starch	0.00 q	7.60 mn	13.38 h-j	18.14 cd	20.81 b	**11.99 B**
irradiated sweet potato starch	0.00 q	6.14 op	9.13 l	12.93 i-k	18.81 c	**9.40 E**
un-irradiated cassava starch	0.00 q	6.92 no	12.57 jk	14.90 fg	18.90 c	**10.66D**
irradiated cassava starch	0.00 q	5.72 p	9.08 l	14.37 gh	16.91 e	**9.22 E**
Mean	**0.00 E**	**7.00 D**	**12.28 C**	**15.86 B**	**20.07A**	
2019/2020						
Control	0.00 p	5.38 o	15.86 hi	20.87 de	23.70 a	**13.16 A**
un-irradiated corn starch	0.00 p	5.94 no	12.17 k	20.02 e	23.26ab	**12.28 B**
irradiated corn starch	0.00 p	5.02 o	12.09 kl	17.25 fg	21.36 cd	**11.15 C**
un-irradiated sweet potato starch	0.00 p	7.79 m	15.06 ij	16.47 gh	20.87de	**12.04 B**
irradiated sweet potato starch	0.00 p	5.84 o	10.93 l	14.23 j	23.29 ab	**10.86 CD**
un-irradiated cassava starch	0.00 p	7.11 mn	12.21 k	18.35 f	22.09 bc	**11.95 B**
irradiated cassava starch	0.00 p	5.48 o	12.11 kl	14.70 ij	20.40 de	**10.54 D**
Mean	**0.00 E**	**6.08D**	**12.92 C**	**17.42B**	**22.14 A**	

Means followed by different letters are significantly different at P ≤ 0.05 level; Duncan's multiple range test.

Table (2): Effect of un-irradiated and irradiated corn, sweet potato and cassava starch edible coatings on respiration rate ml CO_2 /kg/h. of lemon fruits stored at 5 ℃ and 90-95 %RH during 2018/2019 and 2019/2020 seasons

Treatments	Storage period per weeks					
	0	2	4	6	8	Mean
2018/2019						
Control	1.00 s	1.68 n	2.15 g-i	2.57 c	3.64 a	**2.21 A**
un-irradiated corn starch	1.00 s	1.33 o-q	2.06 h-j	2.30 e-g	2.87 b	**1.91 B**
irradiated corn starch	1.00 s	1.27 p-r	1.73 mn	2.31 ef	2.57 c	**1.78 C**
un-irradiated sweet potato starch	1.00 s	1.75 mn	1.81 l-n	1.87 k-m	2.41 de	**1.77 C**
irradiated sweet potato starch	1.00 s	1.14 rs	1.69 n	1.91 j-l	2.50 cd	**1.65 D**
un-irradiated cassava starch	1.00 s	1.22 qr	2.03 i-k	2.18 f-i	2.20 f-h	**1.72 C**
irradiated cassava starch	1.00 s	1.28 p-r	1.40op	1.48 o	2.15 g-i	**1.46 E**
Mean	**1.00 E**	**1.38D**	**1.84C**	**2.09 B**	**2.62 A**	
2019/2020						
Control	1.20 l	2.34 e-g	2.46 c-f	2.70 b	2.74 ab	**2.29 A**
un-irradiated corn starch	1.20 l	1.38 j-l	2.39 d-g	2.48 c-e	2.89 a	**2.07 B**
irradiated corn starch	1.20 l	1.42 jk	1.50 j	2.45 c-f	2.58 bc	**1.83 CD**
un-irradiated sweet potato starch	1.20 l	1.22 l	2.10 h	2.22 gh	2.55 b-d	**1.86 C**
irradiated sweet potato starch	1.20 l	1.47j	1.69 i	2.25 gh	2.55 b-d	**1. 83 CD**
un-irradiated cassava starch	1.20 l	1.22 l	2.10 h	2.22 gh	2.55 b-d	**1.86 C**
irradiated cassava starch	1.20 l	1.25kl	1.42 jk	2.34 e-g	2.29 f-h	**1.70 E**
Mean	**1.20 E**	**1.47 D**	**1.95 C**	**2.38 B**	**2.59 A**	

Means followed by different letters are significantly different at P ≤ 0.05 level; Duncan's multiple range test.

3.1.3. General appearance

Fig. (1) shows the effect of some post-harvest treatments on general appearance of lemon fruits stored at 5±1ºC and 90 % RH, during 2018/2019 and 2019/2020 seasons.

Fruits of all used treatments stored for 2, 4 and 6 weeks kept the highest score of fruit appearance (very good) without significant differences.

At the end of the storage period (after 8 weeks), the highest value of the general appearance score was recorded by fruits treated with un-irradiated cassava starch and irradiated cassava starch, whereas the lowest values were shown by untreated fruits and fruit treated with un-irradiated sweet potato starch without significant differences between them in both seasons.

3.2. Fruit color

3.2.1. Lightness (L*) value

Data presented in Table (3), show that lightness (L*) value was gradually decreased towards the end of the storage period (after 8 weeks).Similar finding was obtained by Ghosh et al.[14] who observed that the increase of the storage period led to a reduction in the fruit colors of Assam lemon fruits through the storage period. As for the effect of the edible coatings, there was a significant differences among all treatments. Fruits coated with irradiated cassava starch gave the highest significant differences and scored the highest (L*) value, while un-coated fruits gave the lowest values in both seasons. This result is in the same line of Shaaban and Hussein [31] who found that cassava starch edible coating gave the highest (L*) value of coated guava fruits.

As for the interaction at the end of the storage period, irradiated cassava starch treatment gave the highest values of L* in the first and second seasons. On the other hand, un-coated fruits exhibited the lowest values of L*, with significant differences in all treatments in the most cases.

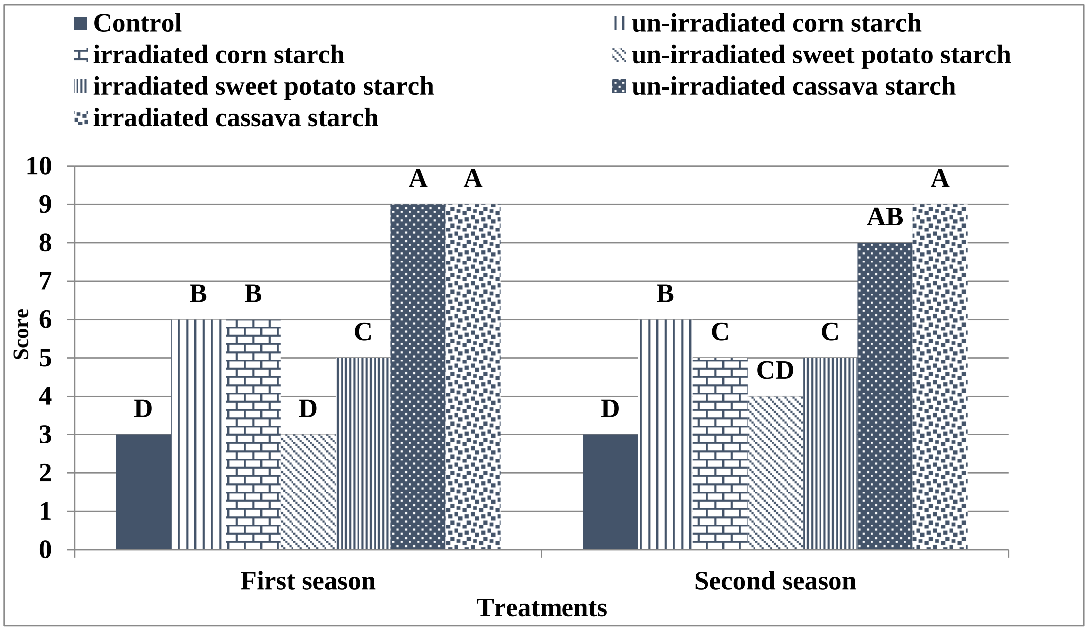

Fig. (1): Effect of un-irradiated and irradiated corn, sweet potato and cassava starch edible coatings on general appearance after 8 weeks of lemon fruits stored at 5 ℃ and 90-95 %RH of during 2018/2019 and 2019/2020 seasons.

Table (3): Effect of un-irradiated and irradiated corn, sweet potato and cassava starch edible coatings on (L*) value of lemon fruits stored at 5℃ and 90-95 %RH during 2018/2019 and 2019/2020 seasons

Treatments	Storage period per weeks					
	0	2	4	6	8	Mean
2018/2019						
Control	79.00 a	76.63 c-f	74.35 i-k	71.80 m-o	70.80 o	**74.52 D**
un-irradiated corn starch	79.00 a	75.29 f-j	74.96 h-j	73.14k-m	71.23 no	**74.72 D**
irradiated corn starch	79.00 a	76.93 c-e	75.84 d-h	72.97 k-m	70.74 o	**75.10 CD**
un-irradiated sweet potato starch	79.00 a	76.46 c-g	75.53 e-i	75.18 g-j	72.41 l-n	**75.71 BC**
irradiated sweet potato starch	79.00 a	77.08 cd	75.56 e-i	74.19 i-k	73.90 jk	**75.95 B**
un-irradiated cassava starch	79.00 a	76.62 c-f	75.83 d-h	75.07 g-j	73.31 kl	**75.97B**
irradiated cassava starch	79.00 a	78.54 ab	77.49 bc	77.06 cd	75.34 f-i	**77.49 A**
Mean	**79.00 A**	**76.79B**	**75.65 C**	**74.20 D**	**72.53 E**	
2019/2020						
Control	78.00 a	75.29 c-e	73.37 f-j	72.40 g-j	64.42 n	**72.70 E**
un-irradiated corn starch	78.00 a	77.57 ab	76.04 bc	68.70 k	65.25 mn	**73.11 DE**
irradiated corn starch	78.00 a	75.41 cd	73.83 d-h	73.38f-j	66.81 lm	**73.49 C-E**
un-irradiated sweet potato starch	78.00 a	76.07 bc	74.05 d-g	71.76 ij	68.22 kl	**73.62 CD**
irradiated sweet potato starch	78.00 a	74.60 c-f	73.49 e-i	72.29 g-j	71.57 j	**73.99 BC**
un-irradiated cassava starch	78.00 a	74.62 c-f	74.44 c-f	73.40 f-i	72.00 h-j	**74.49 B**
irradiated cassava starch	78.00 a	75.99 bc	74.50 c-f	74.32 c-f	73.93 d-g	**75.35 A**
Mean	**78.00 A**	**75.65 B**	**74.25 C**	**72.32 D**	**68.89 E**	

Means followed by different letters are significantly different at P ≤ 0.05 level; Duncan's multiple range test.

3.2.2. Hue angle (h°) value

Results presented in Table (4) show that hue angle (h°) value was decreased (highdensity of yellow color) with the advancement of cold storage period. This result agrees with that obtained by Shaaban and Hussein [31] who observed that the increase of the storage period led to an increase in the density of yellow color of guava fruits.

Significant differences among all treatments were observed in both seasons. The un-coated fruits gave the lowest (h°) value (high density of yellow color) in both seasons. On the other hand, the highest values were recorded with fruits coated with irradiated cassava starch followed by sweet potato starch in the first and the second seasons. In this context, Wijerwardana et al. [34] stated that the biofilm composed of cassava starch delay the ripening of guava fruits and scored lower color (h°) value than that of the un-coated fruits ,while De Aquino et al.[35] who found that guava fruits coated with chitosan combined with cassava starch had higher (h°) values than that of the uncoated fruits.

Regarding the interaction, it was noticed that, at the end of the storage period, fruit coated with irradiated cassava starch recorded the highest h° value (low density of yellow color) , while un-coated fruits scored the lowest one in both seasons.

The decrease of lightness (L*) value and the increase of yellow color density (h°) value through the storage period might be attributed to the production of ethylene which increases the activity of enzymes in fruits and led to the breakdown of chlorophyll and synthesis of carotenoids[36].

Coated fruits with starch showed lower break down in color and maintenance of green color when compared to the un-coated fruits. this result might be related to the effect and the nature of starch edible coating which play an important role as an obstacle against vital process such as respiration and diminish color breakdown, degradation of chlorophyll and retard the transformation to yellow color [37].

Table (4): Effect of un-irradiated and irradiated corn, sweet potato and cassava starch edible coatings on (h°) value of lemon fruits stored at 5 ℃ and 90-95 %RH during 2018/2019 and 2019/2020 seasons

Treatments	Storage period per weeks					
	0	2	4	6	8	Mean
		2018/2019				
Control	109.52 a	99.23 e	97.76 fg	97.06 gh	95.65 h-k	**99.84 C**
un-irradiated corn starch	109.52 a	101.03 d	97.66 fg	96.74 g-i	95.02 jk	**99.99 C**
irradiated corn starch	109.52 a	102.49 bc	97.65 fg	96.68 g-i	95.31 i-k	**100.33 BC**
un-irradiated sweet potato starch	109.52 a	101.70 cd	97.93 e-g	96.61 g-i	94.37 k	**100.03 C**
irradiated sweet potato starch	109.52 a	103.21b	97.98 e-g	97.60 fg	95.13 jk	**100.69 AB**
un-irradiated cassava starch	109.52 a	100.86 d	97.69 fg	97.62 fg	96.12 h-j	**100.36 BC**
irradiated cassava starch	109.52 a	102.92 bc	99.01 ef	98.91 ef	96.61 g-i	**101.39 A**
Mean	**109.52 A**	**101.63 B**	**97.96 C**	**97.32 D**	**95.46 E**	
		2019/2020				
Control	111.06 a	102.50 d	98.57 g-i	97.40 jk	95.56 m	**101.02 D**
un-irradiated corn starch	111.06 a	104.40 c	97.37 jk	97.22 j-l	95.58 m	**101.13 D**
irradiated corn starch	111.06 a	106.49 b	101.10 e	96.56 k-m	93.35 n	**101.71 BC**
un-irradiated sweet potato starch	111.06 a	103.73 c	99.43 fg	97.79 h-j	96.14 lm	**101.63 C**
irradiated sweet potato starch	111.06 a	105.77 b	98.79 f-h	97.70 h-j	97.49 i-k	**102.16 AB**
un-irradiated cassava starch	111.06 a	105.77b	98.79 f-h	97.49 i-k	96.03 m	**101.83 BC**
irradiated cassava starch	111.06 a	104.23 c	99.73 f	99.41fg	97.83 h-j	**102.45 A**
Mean	**111.06 A**	**104.70 B**	**99.11C**	**97.65 D**	**96.00 E**	

Means followed by different letters are significantly different at P ≤ 0.05 level; Duncan's multiple range test.

3.3. Chemical characteristics

3.3.1. Titratable acidity percentage

Data presented in Table (5) revealed that titratable acidity percentage decreased with the advancement of the storage period. This result was conformable with the result of Thapa et al. [27] who concluded that the increase of the storage period decreased significantly the titratable acidity content of sweet orange fruits.

As for the influence of edible coating on titratable acidity percentage, there was a significant differences among all sources of starch in the most cases. In this context, data revealed that fruits coated with irradiated cassava starch gave the highest value of titratable acidity percentage in both seasons. On the other hand, the un-coated fruits (control) recorded the lowest acidity percentage in both seasons. Similar observation was obtained by Rodríguez et al. [38] who stated that coated Andean blackberry with cassava starch scored higher titratable acidity percentage than the uncoated fruits during the storage period.

Regarding the interaction, data revealed that at the end of the storage period, the highest values (4.48 and 4.67 %) were recorded by fruits coated with irradiated cassava starch in the two successive seasons. On the other hand, the un-coated fruits at the end of storage period gave the lowest percentage of acidity in both seasons.

The decrease of acidity during storage period might be attributed to the oxidation of organic acids such as ascorbic or citric acids which are the main components in the respiration process[39] and as carbon skeletons (from their carboxyl groups) for the synthesis of new compounds (e.g., flavor compounds)[40] .The highest percentage of titratable acidity in the coated fruits with irradiated cassava starch might be due to the ability of cassava starch in forming thin layer around fruits which delays the ripening of fruits and reduces the rate of the vital processes such as respiration which decreases the consumption of organic acids[41].

Table (5): Effect of un-irradiated and irradiated corn, sweet potato and cassava starch edible coatings on Tititratable acidity % of lemon fruits stored at 5 ℃ and 90-95 %RH during 2018/2019 and 2019/2020 seasons

Treatments	Storage period per weeks					
	0	2	4	6	8	Mean
2018/2019						
Control	5.50 a	4.68 f	4.42 i-k	3.87 m	3.84m	**4.46 D**
un-irradiated corn starch	5.50 a	4.72 f	4.48 hi	3.87 m	3.84 m	**4.48 D**
irradiated corn starch	5.50 a	5.24 c	4.88 e	4.19 l	4.16 l	**4.79 B**
un-irradiated sweet potato starch	5.50 a	5.15 d	4.40 jk	3.84 m	3.76 n	**4.53 C**
irradiated sweet potato starch	5.50 a	4.85 e	4.83 e	4.59 g	4.49 h	**4.85 A**
un-irradiated cassava starch	5.50 a	5.35 b	4.45 h-j	4.40 jk	4.37 k	**4.81 B**
irradiated cassava starch	5.50 a	5.35 b	4.58 g	4.45 h-j	4.48 hi	**4.87 A**
Mean	**5.50 A**	**5.05B**	**4.58 C**	**4.17D**	**4.13E**	
2019/2020						
Control	6.00 a	4.32 j-m	4.22 k-n	4.05 n	4.05 n	**4.53 E**
un-irradiated corn starch	6.00 a	4.66 e-h	4.55 g-i	4.32 j-l	4.10 n	**4.73 D**
irradiated corn starch	6.00 a	5.37 c	4.38i-k	4.17 mn	4.17 l-n	**4.82 C**
un-irradiated sweet potato starch	6.00 a	4.83 de	4.53 hi	4.19 l-n	4.19 l-n	**4.75 CD**
irradiated sweet potato starch	6.00 a	5.60 b	4.64 f-h	4.53 hi	4.16 m-n	**4.99 B**
un-irradiated cassava starch	6.00 a	4.80 d-f	4.43 ij	4.40 ij	4.35 j-l	**4.80 CD**
irradiated cassava starch	6.00 a	5.20 c	4.84 d	4.72 d-g	4.67 d-h	**5.09 A**
Mean	**6.00 A**	**4.97B**	**4.51 C**	**4.34 D**	**4.24 E**	

Means followed by different letters are significantly different at P ≤ 0.05 level; Duncan's multiple range test.

3.3.2. Soluble solids content:

It is clear from the results presented in Table (6) that soluble solids content of fruits gradually decreased with the advance of the cold storage period. Similar result was obtained by Ma et al. [42] who found that the prolongation of the storage period was accompanied by a decline in the total soluble solids of stored Eureka lemon fruits.

As for the effect of different treatments, it was found that lemon fruits coated with irradiated sweet potato and cassava starch exhibited the highest percentage of soluble solids content, while the un-coated lemon fruits scored the lowest one during the two successive seasons. The current results are in the same line of Wijerwardana et al. [34] on guava fruits, who reported that fruits coated with starch had higher effect in maintaining soluble solids content, probably due to the effect of edible coating film which was formed on the surface of the fruits and played an important role as a barrier against moisture loss, delaying dehydration and improving the fruit quality.

As for the interaction, data revealed that at the end of the storage period, the un-coated fruits gave the lowest percentage of soluble solid content in the two successive seasons. On the other hand, fruits coated with irradiated cassava starch edible coating gave the highest percentage of soluble solids content in both seasons.

The decrease of soluble solids content during the storage period might be attributed to the effect of the respiration process which consumed sugars and organic acids resulting in the acceleration of fruit senescence and enzymatic reactions that hydrolysis sugars [43].

Table (6): Effect of un-irradiated and irradiated corn, sweet potato and cassava starch edible coatings on soluble solids content % of lemon fruits stored at 5 ℃ and 90-95 %RH during 2018/2019 and 2019/2020 seasons

Treatments	Storage period per weeks					
	0	2	4	6	8	Mean
2018/2019						
Control	9.63 a	9.20 de	8.83 fg	8.10 jk	8.05 k	**8.76 E**
un-irradiated corn starch	9.63 a	9.53 a-c	9.20 de	8.70 gh	8.40 h-j	**9.09 D**
irradiated corn starch	9.63 a	9.53a-c	9.50 a-d	9.30 b-e	8.33 i-k	**9.26 BC**
un-irradiated sweet potato starch	9.63 a	9.40 a-e	9.25 c-e	9.10 ef	8.38 ij	**9.15 CD**
irradiated sweet potato starch	9.63 a	9.57 ab	9.30 b-e	9.17 e	9.10 ef	**9.35 AB**
un-irradiated cassava starch	9.63 a	9.40 a-e	9.25 c-e	9.10 ef	8.57 g-i	**9.19 CD**
irradiated cassava starch	9.63 a	9.60 ab	9.50 a-d	9.30 b-e	9.10 ef	**9.43 A**
Mean	**9.63 A**	**9.46 B**	**9.26C**	**8.97D**	**8.56 E**	
2019/2020						
Control	10.00 a	9.73 bc	8.90 l-n	8.77 no	8.52 p	**9.18 D**
un-irradiated corn starch	10.00 a	9.45 d-f	9.17 h-k	9.03 j-m	8.73 n-p	**9.28 CD**
irradiated corn starch	10.00 a	9.62 b-d	9.48 de	9.15 i-k	8.80m-o	**9.41 AB**
un-irradiated sweet potato starch	10.00a	9.45 d-f	9.43 d-g	8.97 k-n	8.65 op	**9.30 BC**
irradiated sweet potato starch	10.00a	9.80ab	9.40 d-h	9.22f-j	8.77 no	**9.44 A**
un-irradiated cassava starch	10.00a	9.50 c-e	9.20 g-k	9.06 j-l	8.65op	**9.28 CD**
irradiated cassava starch	10.00 a	9.77 ab	9.35 e-i	9.17 h-k	8.83 l-o	**9.43 A**
Mean	**10.00 A**	**9.62 B**	**9.28 C**	**9.05 D**	**8.71 E**	

Means followed by different letters are significantly different at P ≤ 0.05 level; Duncan's multiple range test.

3.3.3. Ascorbic acid concentration

Data presented in Table (7) showed that ascorbic acid concentration decreased with the progress of the storage period. Similar finding was obtained by Ghosh et al. [14] who observed that the increase of the storage period led to a decrease in ascorbic acid concentration in lemon fruits especially at the end of the storage period.

As for the effect of edible coatings, data show that the highest concentration of ascorbic acid was obtained in fruits coated with both irradiated sweet potato and cassava starch edible coatings without significant differences between them in the two successive seasons. On the other hand, the un-coated fruits exhibited the lowest value of ascorbic acid in both seasons. This observation was in the same line of Shaaban and Hussein [31] who found that guava fruits coated with cassava starch edible coating scored high concentration of ascorbic acid content and Wibowo et al. [44] who observed that coated red chili with sweet potato starch edible coating had the highest concentration of ascorbic acid during the storage period.

As for the effect of the interaction, it could be concluded that after at the end of the storage period, fruits coated with irradiated cassava starch gave the highest concentration of ascorbic acid in both seasons. On the other hand, the un-coated fruits scored the lowest concentration of ascorbic acid (35.65 and 41.85 mg/100ml juice) during the two successive seasons.

Coated fruits had higher concentration of ascorbic acid compared to un-coated fruits, which might be due to the modified atmosphere around fruits which reduces the concentration of oxygen around the fruits, slows the respiration process and delay the enzymatic oxidation of both ascorbic acid and phenols to dehydroascorbic acid. From another viewpoint, the highest concentration of ascorbic acid and polyphenols in coated fruits might be related to the low increment in the activity of polyphenoloxidase in comparison to the un-coated fruits[33].

Table (7): Effect of un-irradiated and irradiated corn, sweet potato and cassava starch edible coatings on ascorbic acid (mg/100ml)of lemon fruits stored at 5 ℃ and 90-95 %RH during 2018/2019 and 2019/2020 seasons

Treatments	Storage period per weeks					
	0	2	4	6	8	Mean
			2018/2019			
Control	65.00 a	55.33 f	49.98 g	47.20 i	35.65 l	**50.63 E**
un-irradiated corn starch	65.00 a	64.26 ab	49.95 g	48.00 hi	44.02 j	**54.25 D**
irradiated corn starch	65.00 a	64.00 a-c	56.83 ef	48.79 g-i	44.74 j	**55.87 C**
un-irradiated sweet potato starch	65.00 a	64.26 ab	57.12 e	49.19 gh	41.60 k	**55.43 C**
irradiated sweet potato starch	65.00 a	64.25 ab	63.50 a-c	62.48 c	48.15 hi	**60.68 A**
un-irradiated cassava starch	65.00 a	57.87 e	57.12 e	57.12 e	48.00hi	**57.02 B**
irradiated cassava starch	65.00 a	64.00 a-c	63.31 bc	60.69 d	50.01 g	**60.60 A**
Mean	**65.00 A**	**62.00 B**	**56.83 C**	**53.35 D**	**44.60 E**	
			2019/2020			
Control	66.00 a	57.35 c	55.33 c-e	47.67 kl	41.85 m	**53.64 D**
un-irradiated corn starch	66.00 a	57.35 c	55.67 c-e	49.95 h-j	49.61 i-k	**55.72 C**
irradiated corn starch	66.00 a	64.15 ab	62.48 b	52.07 f-h	51.77 g-i	**59.29 A**
un-irradiated sweet potato starch	66.00 a	62.40 b	57.07 c	49.63 i-k	48.98 jk	**56.82 B**
irradiated sweet potato starch	66.00 a	65.45 a	64.12 ab	55.67 c-e	46.09 l	**59.46 A**
un-irradiated cassava starch	66.00 a	56.00 cd	54.74 de	54.15 d-f	53.55 e-g	**56.89 B**
irradiated cassava starch	66.00 a	64.24 ab	57.15 c	57.04 c	54.00 d-f	**59.69 A**
Mean	**66.00 A**	**60.99 B**	**58.08 C**	**52.31 D**	**49.41 E**	

Means followed by different letters are significantly different at P ≤ 0.05 level; Duncan's multiple range test.

CONCLUSION

It could be concluded from the current study that lemon fruits coated with irradiated cassava starch followed by irradiated sweet potato starch significantly decreased the fruit deterioration rate during the storage and increased the storage period which was clearly shown by decreasing weight loss and respiration rate. This was also revealed through preserving fruit color and maintaining the chemical constituents of lemon fruits during the cold storage period.

CONFLICT OF INTEREST STATEMENT

There is no conflict of interest

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