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Development of an Automatic Temperature Control System to Extend shelf life of Coated Apple Fruits

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ABSTRACT

The aim of this study was to develop a control system for the preservation purposes of apple fruits. Chemical and physical changes of Lebanese (Mauls domestics 'Golden Delicious) apple were studied primarily under four preserving temperatures namely -2, -1, 0, 1 ºC symbolled with T_1, T_2, T_3, T_4 to be tested with two types of edible coatings which were paraffin wax, C_1 and sodium alginate, C_2. Results reflected the importance of controlling temperature in keeping the quality parameters of apple which included Ascorbic acid content, sugar content, weight loss, taste, and color in satisfactory range. C_1 and T_3 recorded the best quality for apple during preservation period which was three months. The study recommended to control the temperature with C_1T_3.

INTRODUCTION

Fruits and vegetables have a metabolic activity. They are living tissues that breathe and release heat. As a result of the metabolic activity, fruits are converted from one form to another. The fruit is exposed to spoilage during harvesting and storage by bacteria, enzymes and microorganisms, where changes occurrence led to make the fruit unappetizing and unacceptable in taste and smell. The nutritional value of a single apple was found to be sugars of 23.9 g/100g vitamin C, 11mg/100g -dietary fiber 5.5 g (22%) -the protein 0.6 g-calcium 14 mg **Bump, (1989)**. The amount of Egypt's imports of apples increased from 0.57 Mg in 2008 to about 5.1 Mg in 2019 **FAO, (2019)**. **Shoaib et al., (2012)** reported that Vegetables and fruits shelf life are extended by using low temperatures. **Rao, (2015)** stated that the optimum temperature for preserving apple fruits is from 0 °C to 4 °C. Under these conditions, the least amount of ethylene is released, and the fruits themselves do not lose their appearance or taste. **Nissen et al., (2016)** reported that refrigeration has long been used to regulate ripening and extend the storage life of apples. Edible coatings enhance the exterior and interior quality attributes of a variety of products, as well as minimize dehydration and oxidation and the unfavorable changes they cause in color, flavor, and texture **Kabir et al., (2016)**. Wax and other coatings can prolong the shelf life and microbiological stability of fresh vegetables by delaying ripening and senescence. **Sripong et al., (2020)** reported that the treatment of paraffin wax could reduce crown rot diseases and maintain some plant defense mechanism such as total phenolic. **Vázquez et al., (2016)** Discussed that Edible coatings such as alginate and chitosan have the ability to reduce changes in the overall degradation of anthocyanin's and prevent color degradation during storage. The advantage of alginate is reducing the shrinkage of food products and maintaining their moisture, color and odor. Edible coating is most typically applied to fruits, such as fresh apples, to retain their color, firmness, sensory qualities, and shelf life. It also has some antibacterial capabilities. Controlled atmosphere storage is a useful technology for keeping the quality of fresh fruits and extending their shelf-life **Valdez Fragoso and Mújica-Paz (2016); Wendt et al., (2022).** Controlling preserving temperature is expected to assure maintaining preserving temperature during all the storage time.

Objectives of this study were as follows:

1- Investigate how edible coatings films can preserve apple physical properties with varied range of temperatures.

2- Develop a simple automatic control system for temperature to be suitable for preservation structures like large refrigerators to facilitate preservation process in commercial scale.

MATERIAL AND METHODS

The study was conducted in a special laboratory equipped and designated for experiment during the year 2020 in Damietta city, Damietta governorate, Egypt. The experiments targeted apple fruits (Mauls domestics 'Golden Delicious) as perishable fruit, which contain large amounts of water that causes a number of physiological and pathological disorders, and consequently causes a reduction in storage and shelf life. This experiment included three variables which were preserve temperature and edible coating film type to be examined with two systems of controlling temperature of refrigerators. First system based on built-in refrigerator thermostat and the other was a developed automatic control system.

2.1 Materials

2.1.1 Refrigerators

Four refrigerators 220 V, with 60 cm height, 55 cm width and 45 cm depth dimensions and 58 l capacity equipped with freezing shelf in addition to two normal refrigeration shelves were used to preserve the fruits. Isolation material between walls of refrigerators according to manufacturer was polyurethane which has insulation value of 0.022 w/m. ^{o}k.

2.1.2 Temperature automatic control system design and components

A real time closed loop control system has been developed to control the temperature of any preserving structure or device like huge or normal refrigerators. Arduino max 6675 Control board was used to build the control system. Programming of the control system was through open-source software from the manufacturer and the fed to the board PLC. The board is supported by a digital screen to show required data and a numeric panel to enter digital data as shown in figure 1.

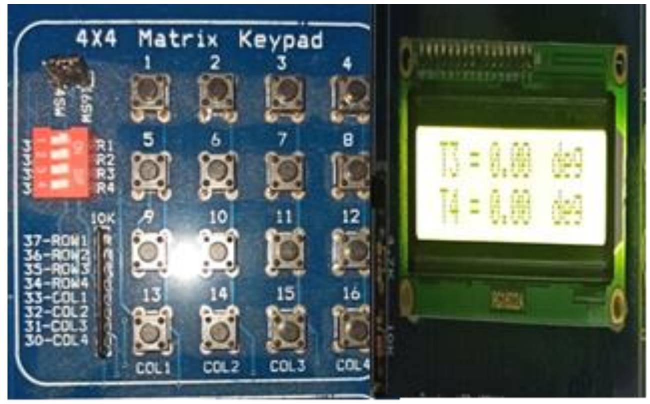

Fig. 1 Numeric panel and data screen of the control board

The system design was to adjust the temperature of refrigerating device as required by collecting temperature readings from eight corners from the refrigerating room and calculate their average to describe the temperature inside. Thermocouple temperature sensing kit K type sensing thermocouple kit which is compatible with the used control board. Temperature sensor reading range is -50 to 150 ^{o}C with 0.25 ^{o}C temperature resolution. Figure 2 shows the control system data flow chart. Operator will manually enter the desired operating temperature T_{oper} through an included panel in the control system in order to enable the system to compare between this value and the calculated average T_{avg} which comes from the eight sensors and calculated by the programmable logic control (PLC) of the control system. When T_{avg} is greater than T_{oper} then the PLC will give the relay the signal to conduct the operation signal to the electric components of the refrigerator.

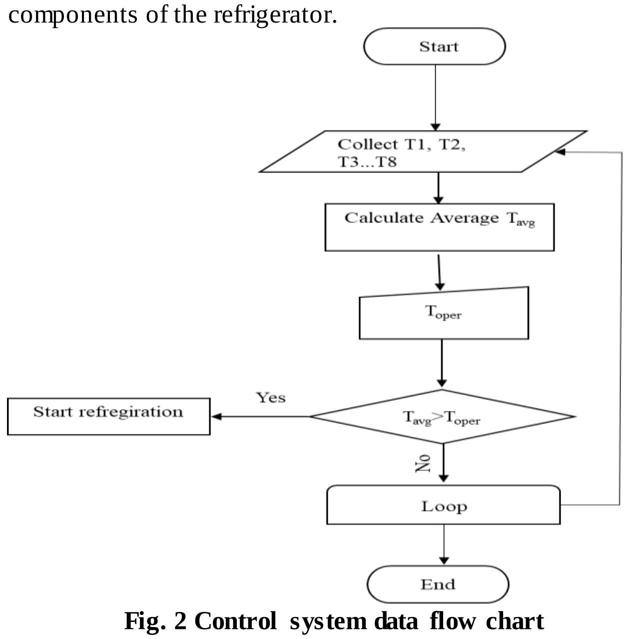

Fig. 2 Control system data flow chart

At any other case the system will keep monitoring T_{avg} to decide the need to start refrigeration process. Figure 3 shows a diagram for the connections between the components of the proposed control system

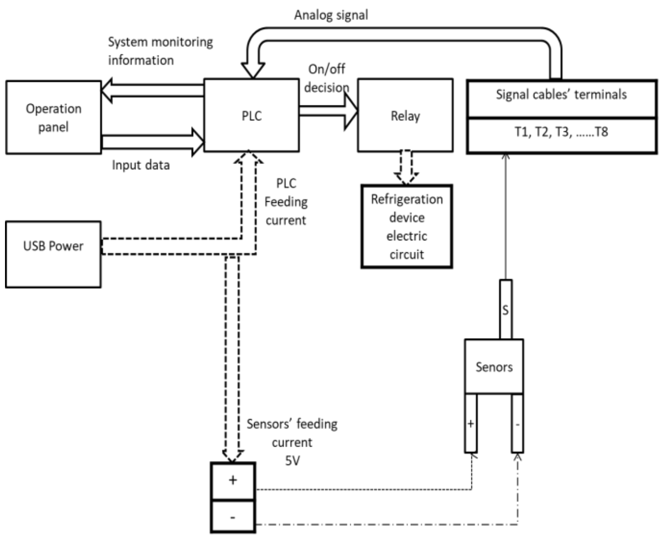

Fig. 3 Connection and layout of the control system physical components

Eight sensors model were used, A test board was fit on the main control board to collect the electric current input from the board to the sensors and feed the PLC with the readings of the sensor.

2.1.3 Temperature measurement

Temperature inside each refrigerator was measured using a digital thermometer 0.1 °C accuracy with measuring range -50 to 300 °C.

2.1.4 Fruit weighing

Fruit weight was measures using a digital balance 20 kg capacity with 0.001 g accuracy.

2.2 Methods

2.2.1 Variables

Four temperatures namely T_1= -2, T_2= -1, T_3= Zero and T_4 = 1ºC, which considered suitable range for apple preservation with two edible coating films included paraffin wax (C_1) and sodium alginate (C_2). Two temperature control methods were used, using refrigerator built-in thermostat and the other was with automatic control system. Experiments were divided into two phases first one was with refrigerator built-in temperature control (R) and the second phase was after finishing the first one using automatic control system (C) using the same refrigerators.

2.2.2 Apple fruit preparation

High-quality fresh apples were selected and brought from an imported shipment. Selection of apples considered homogeneity of size and weight as possible. Apples has been washed well and air dried, and then placed in plastic plates on the refrigerator shelves. Each plate has ten apples away from each other's to act one treatment. the fruits are then coated with prepared edible films. The treated fruits were air-dried and placed on plastic containers, then stored at the mentioned temperatures for three months, and then samples were taken periodically every 15 days for sensory assessments, while physical and chemical analysis were done every 45 days during the experiment.

2.2.3 Edible coatings preparation

2.2.3.1 Preparing sodium alginate coating

Sodium alginate powder ($NaC_6H_7O_6$) was used as a primary ingredient in edible coatings Formulation. Preparation of alginate solution ranging from 0.5 to 3 percent (weight/volume) concentration. Sodium alginate solution was prepared by dissolving 7.5 g of its powder in 500 ml of distilled water, stirring on cold until dissolution, using an electric stirrer, adding 0.225 ml of glycerol (3% concentration) to the distilled water and sodium alginate with stirring. Then the apples were dipped in this mixture for ten minutes.

2.2.3.2 Preparing paraffin wax:

Paraffin wax was prepared by melting 200 g of paraffin wax in a stainless-steel container on a hot plate at 60 ° C when the wax was completely melted; the hot plate was left at 50 ° C before treating the apple fruits with wax. The apple fruits are dipped in a layer of melted paraffin wax for about a 2 second and the paraffin hardens directly on the surface of the fruit after removing it from the molten wax.

2.2.4 Temperature adjustment and control

In the first phase of experiments, we used the traditional built in temperature control system based on refrigerator thermostat (R). The freezing room was used in each refrigerator for minus temperatures while zero and 1 temperatures were in the normal shelves. Level of temperature changed till reaching the decided temperature inside the refrigerator or freezing chamber till the inner thermostat of refrigerator gets power off and then the temperature was measured to decide if it equals the decided level or not. In the second phase of the experiments, refrigerator thermostat has been replaced by the control system (C) with modifications in electric circuits of the refrigerator in order to enable the control system to get the refrigerator ON or OFF according to the required temperature.

2.2.5 Measurements

The fruit quality evaluation included sensory and chemical evaluation. Chemical quality parameters included Ascorbic acid or vitamin C content in addition to sugar content. Measurements were at the beginning of experiments and repeated with 45 days frequency till the end of the experiments.

2.2.5.1 Ascorbic acid

Ascorbic acid content (g/100g) were investigated by dissolving 42 mg sodium bicarbonate into distilled water. Making of the standard solution was by dissolving 100 mg ascorbic acid with 100ml of 4% concentration oxalic acid solution in a standard flask 100 ml and working standard solution (100 mg/ml). End point is the appearance of pink color which persists for few minutes. The amount of dye consumed is equivalent to the amount of ascorbic acid then sample extraction was 0.5 to 5 g based on the required sample volume.

2.2.5.2 Total soluble sugar

Sulfuric acid 95.5% grade was used as a reagent which had specific gravity 1.84. Phenol, 80% by weight, prepared by adding 20 g of glass distilled water to 80 grams of redistilled reagent grade phenol. This mixture forms a water-white liquid that is readily pipeted. Certain preparations have been known to remain water-white after a years' storage, while others turn a pale yellow in 3 or 4 months. In order to obtain good mixing. The mixture was put in tubes that allowed to stand 10 minutes, then they are shaken and placed for 10 to 20 minutes in a water bath at 25°C to 30°C for several hours. Before taking readings, we were sure that the color is stable for several hours and readings may be made later if necessary. Density of light for samples was measured by photo-spectrometer at 490 nm for hexoses and 480 nm for pentoses and uronic acids. Blanks are prepared by substituting distilled water for the sugar solution. All solutions are prepared in triplicate to minimize errors. Termination with cellulose lint.

2.2.5.3 Apple weight loss

The weight loss (WL) was calculated by calculating the average for each group of apples over the course of the experiment. The weight was calculated every 15 days during storage, and in the end, the weight was compared at the specified temperatures and the edible coatings for each group. To determine the effectiveness of alginate coatings as moisture-barriers, the WL of apple slices were calculated by comparing the weights of samples during 90 days of storage with their initial weights.

2.2.5.4 Sensory evaluation

Consumers use sensory evaluation to evaluate the flavor of the fruit because it typically produces a more accurate result how humans perceive flavor, smell, and color. Fruit taste is measured by Preference/Acceptable tests where panelist rate product from 0 (extremely dislike) to 10 (extremely like). In this experiment, the uncoated and coated fruits were subjected to sensory evaluation by a panel of 10 judges during storage for appearance, color, texture, odor, taste and general acceptability over a period of 30 days during cold storage for 3 months.

Table 1 evaluation grades of apple fruit sensory specifications

Grade	Taste Evaluation	Color evaluation
0-2.9	Very Poor	Dark brown to musty
3-5.9	Poor	Light brown
6-8.9	Fair, limited use	Brown spots
9-10	Normal	Original

RESULTS AND DISCUSSION

3.1. Ascorbic acid

Results listed in table 2 showed the effect of different coating materials and temperatures on Ascorbic acid content variation for apple fruits during the study time periods of both controlled and normal treatments.

Table 2. Ascorbic acid content, g/100g through experiments time period for controlled and non-controlled treatments.

Treatment		Initial	45 days	90 days	Change
R	C_1T_1	8.21	6.37	4.53	3.68
	C_1T_2	8.15	6.46	4.76	3.39
	C_1T_3	7.78	7.58	7.38	0.40
	C_1T_4	6.62	5.81	5.00	1.62
	C_2T_1	6.95	4.67	2.38	4.57
	C_2T_2	7.96	5.77	3.57	4.39
	C_2T_3	7.56	7.35	7.14	0.42
	C_2T_4	8.12	6.56	5.00	3.12
C	C_1T_1	8.21	7.375	6.54	1.67
	C_1T_2	8.15	7.465	6.78	1.37
	C_1T_3	7.78	7.605	7.43	0.35
	C_1T_4	6.62	6.315	6.01	0.61
	C_2T_1	6.95	5.585	4.22	2.73
	C_2T_2	7.96	6.7	5.44	2.52
	C_2T_3	7.56	7.29	7.02	0.54
	C_2T_4	8.12	7.575	7.03	1.09

Automatically controlled treatments showed higher ability to preserve ascorbic acid content. Least change in Ascorbic acid content was at C_1T_3 for both R and C treatments. Greatest change was with non-controlled C_2T_1 treatment while using control system for the same treatment led to reduce the final change by 74.6%. Figure 4 clarifies a comparison between the change in Ascorbic acid content for R and C treatments. It was clear that C_2T_1 treatment recorded the highest variation in Ascorbic acid during preservation period. The results obtained for T_3 was compatible with results of **Kumar et al., (2022); and Abbasi et al., (2009)**, for different types of fruits. Combining zero °C temperature with Sodium alginate gave the same effect on keeping the content of ascorbic acid for carambola **Gol et al., (2015)** and Guava **Nair et al., (2018).**

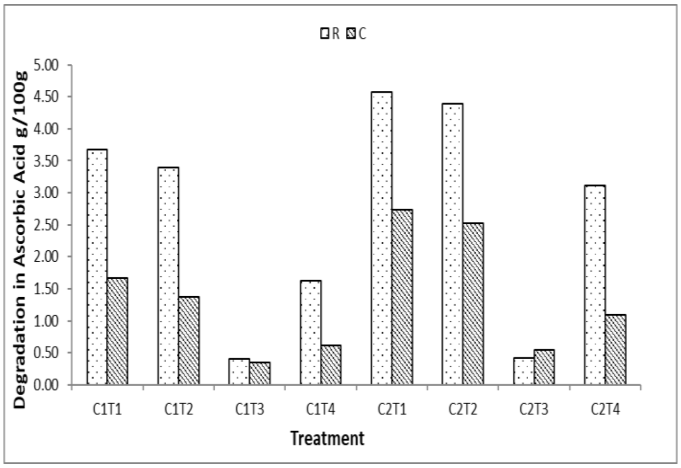

Fig 3. Comparison of the effect of different treatments on Ascorbic acid content through preservation time period.

4.2 Sugar content

Results indicated that, automatic control system led keeping the sugar content compared to non-controlled treatments. Data listed in table 3 showed that least variation in sugar content was 0.35 at C_1T_3 controlled treatment. Greatest variation in sugar content was at non-controlled C_2T_1 treatment.

Table 3. Sugar content, g/100g through experiments time period for controlled and non-controlled treatments.

Treatment		Initial	45 days	90 days	Change
R	C_1T_1	11.10	9.26	7.42	3.68
	C_1T_2	10.60	8.91	7.21	3.39
	C_1T_3	9.80	9.60	9.40	0.40
	C_1T_4	10.00	9.19	8.38	1.62
	C_2T_1	10.20	7.92	5.63	4.57
	C_2T_2	10.50	8.31	6.11	4.39
	C_2T_3	10.80	10.59	10.26	0.54
	C_2T_4	10.10	8.54	6.98	3.12
C	C_1T_1	11.10	10.27	9.43	1.67
	C_1T_2	10.60	9.92	9.23	1.37
	C_1T_3	9.80	9.63	9.45	0.35
	C_1T_4	10.00	9.70	9.39	0.61
	C_2T_1	10.20	8.84	7.47	2.73
	C_2T_2	10.50	9.24	7.98	2.52
	C_2T_3	10.80	10.53	10.38	0.42
	C_2T_4	10.10	9.56	9.01	1.09

Using control system led to decrease loss in sugar content compared to non-controlled treatments. T_3 showed higher ability to reduce the degradation in apple sugar content. In average using control system could reduce loss in sugar content by 21.57% at C_2T_1 to 0.51% at C_1T_3. This could show how could controlling temperature reduce the negative effect of poor preserving conditions of coatings and temperature when considering that C_2T_1 showed the least ability to keep apple sugar content. These results in agreement with **Wang et al., (2022)** that Zero °C showed higher performance for keeping shelf life of apple fruits.

4.3 Weight loss

Table 4 lists the weight loss of apple fruits in grams during 90 days of preservation. The table also shows the average of the treatment under both controlled and non-controlled conditions. Average weight loss reached the greatest value with C_2T_1 treatment, while the lowest was with C_1T_3 whether with controlled or non-controlled treatments.

Table 4. Weight loss, g for controlled and non-controlled treatments.

Treatment	R	C	Average
C_1T_1	15.3	12.0	13.65
C_1T_2	14.8	11.2	13.00
C_1T_3	8.2	6.6	7.40
C_1T_4	11.7	10.2	10.95
C_2T_1	23.2	19.0	21.10
C_2T_2	19.5	17.2	18.35
C_2T_3	9.6	8.2	8.90
C_2T_4	14.2	10.8	12.50
Average	14.56	11.90	

It was noticeable that controlling the temperature led to decrease the weight loss. Variation in weight between minimum and maximum recognized weight loss was 65.26% and 64.65% for controlled and non-controlled treatments. This might be in the reverse direction of the trend of results from the point of the role of controlling temperature. On the other hand, the when comparing average weight loss for controlled treatments with the one of non-controlled treatments; we find that controlling temperature led to save the weight by 13.74% of average weight loss of non-controlled treatments. Reduction of water movement due to lowering temperature was supported by edible coatings as it reduced the chilling sensitivity of apples which made the T_4 temperature showing better ability to preserve apple **Bai et al., (2003); Moldao et al., (2003); Cong et al., (2007); Maqbool et al., (2011).**

4.4 Sensory evaluation

Results of both color and taste of apple are shown in tables 5 and 6. In general, T_3 temperature showed the best ability to resist the changes in sensory specification of apple as shown in tables 4 and 5. These results were in agreement with **Wang (2003); Peck et al., (2006); Veraverbeke and Nicolaï (2007)**. Non-controlled treatments C_1T_1, C_1T_2, C_2T_1, C_2T_2, and C_2T_3 Reached the brown color with difference in spreading grade in apple tissues.

Table 5. degradation of apple color grade under different temperatures and coating materials under controlled and non-controlled temperature.

Treatment		Test time						Average
		1	2	3	4	5	6	
R	C_1T_1	10	7	5	5	5	5	6.17
	C_1T_2	10	10	10	7	5	5	7.83
	C_1T_3	10	10	10	10	9.5	9	9.75
	C_1T_4	10	10	10	9	7	7	8.83
	C_2T_1	10	7	5	5	3	3	5.50
	C_2T_2	10	7	5	5	3	3	5.50
	C_2T_3	10	10	10	10	9.4	8.9	9.72
	C_2T_4	10	10	10	8	7	5	8.33
C	C_1T_1	10	10	9	8	8	7	8.67
	C_1T_2	10	10	10	8	7	6	8.50
	C_1T_3	10	10	10	10	10	10	10.00
	C_1T_4	10	10	10	10	8	8	9.33
	C_2T_1	10	8	8	7	5	3	6.83
	C_2T_2	10	10	9	7	6	5	7.83
	C_2T_3	10	10	10	10	9.5	10	9.92
	C_2T_4	10	10	10	9	8	6	8.83

Comparing this system to the facing ones with the automatic control system we could find that controlling temperature led to decrease degradation rate of apple color which led to increase the final degree of color. C_1 cover led to better keeping for the apple color. Apple taste followed the same trend of results as color. This is expected as the zero temperature and coating reduce the enzymes activities that causes fruit spoilage like Polyphenol oxidase **Hamdan et al., (2022)**. Figures 4 and 5 shows a comparison between the average taste grades of different treatments under automatically controlled and non-controlled control treatments. C_1T_3 and C_2T_3 treatments which showed higher ability to keep the quality of sensory specifications were close in the final grade value but using control system led to keep the quality of apples at the same original value.

Table 6. degradation of apple taste grade under different temperatures and coatings materials under controlled and non-controlled temperature.

Treatment		Test time						Average
		1	2	3	4	5	6	
R	C_1T_1	10	7	6	5	3	0	5.17
	C_1T_2	10	8	6	5	4	0	5.50
	C_1T_3	10	9	8	8	5	2	7.00
	C_1T_4	10	8	8	7	5	0	6.33
	C_2T_1	10	6	5	3	2	0	4.33
	C_2T_2	10	6	5	4	2	0	4.50
	C_2T_3	10	9	7	7	5	1	6.50
	C_2T_4	10	8	7	5	3	0	5.50
C	C_1T_1	10	10	9	7	6	5	7.83
	C_1T_2	10	10	9	7	7	6	8.17
	C_1T_3	10	10	10	10	9	9	9.67
	C_1T_4	10	10	10	8	7	7	8.67
	C_2T_1	10	10	8	6	4	3	6.83
	C_2T_2	10	10	8	6	5	4	7.17
	C_2T_3	10	10	10	9	8	8	9.17
	C_2T_4	10	10	10	8	7	6	8.50

It was clearer in taste grades, that controlling temperature increased the average of taste quality from 7.0 to 9.67 and from 6.5 to 9.17 for the treatments C_1T_3 and C_2T_3 respectively.

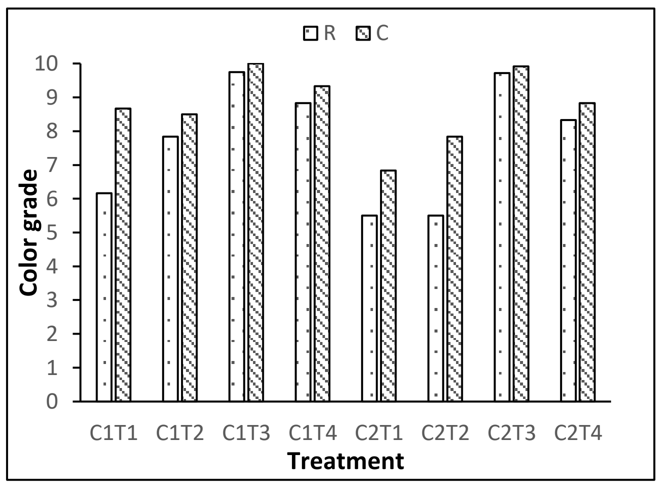

Fig 4. Comparison of the effect of R and C treatments on keeping apple color grade through preservation time period.

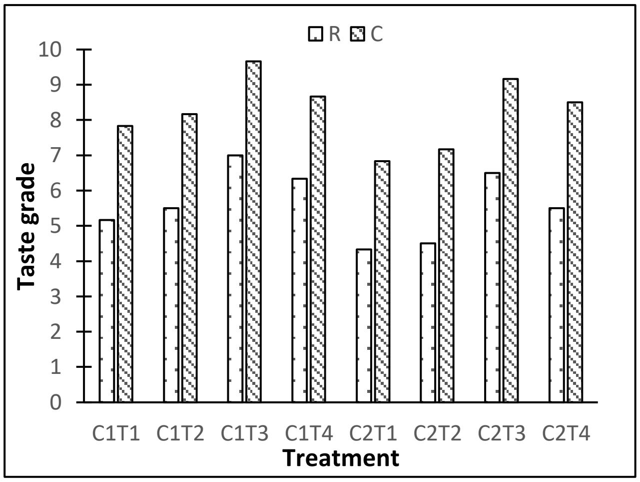

Fig 5. Comparison of the effect of R and C treatments on keeping apple taste quality.

To assure the role of controlling temperature in these two treatments the minimum grades for C_1T_3 and C_2T_3 were 2 and 1 with R control while they were 9 and 8 for C controlling, respectively.

CONCLUSION

An automatic control system was developed to maintain the shelf life of apple fruits within 3 months and to achieve best possible quality of apples by reducing spoilage during storage periods through the use of edible coating The results of this study indicate that the coating of sodium alginate and edible paraffin wax has a significant effect on the retention of apple fruit quality during storage. The system was designed to keep refrigerator temperature adjusted to the required one through all storage period. Quality parameters included the change of Ascorbic acid, sugar content, and weight loss beside sensory evaluation which included taste and color. Results showed that controlling the temperature led to enhance the quality parameters of apple compared to non-controlled refrigeration temperature control. In general, automatically controlled treatments showed higher ability to preserve apple if compared to the normal treatments. Zero ^{o}C temperature was recommended for better results of preservation when compared to other temperatures at all treatments. Quality of preservation indices clarified that paraffins wax showed higher ability than Sodium alginate to preserve apple fruits. Zero ^{o}C temperature showed that it could be recommended for better results of preservation when compared to other temperatures at all treatments as it recorded best values of quality parameters. Paraffin wax coating showed better conservation ability compared to Sodium alginate wax. The study showed the importance of controlling the storage temperature and use Paraffin Wax as coating material with Zero ^{o}C temperature. Future studies may be recommended to study the effect of using different coating materials and study the possible effect of temperature sensors distribution inside the refrigerator especially in large ones.

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CONFLICT OF INTEREST:

The authors declare that they have no conflict of interest.

AUTHORS CONTRIBUTION

Elnemr, M.K. ; Zeid, S. M developed the concept of the manuscript. sanaa wrote the manuscript. All authors checked and confirmed the final revised manuscript.

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تطوير نظام تحكم أوتوماتيكي لإطالة العمر التخزيني لثمار التفاح المطلية

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تهدف هذه الدراسة إلى الحفاظ على ثمار التفاح وإطاله العمر التخزينى لها والحفاظ على الخصائص الفيزيائية والكيميائية لها من خلال تطوير نظام تحكم آلى في درجة الحرارة مع استخدام الأغلفة الصالحة للأكل تحت درجات حرارة مختلفة ، أجريت الدراسة الحالية خلال عام 2020 على صنف التفاح اللبنانى (Mauls domestics 'Golden Delicious) شملت درجات الحرارة تحت الدراسة أربعة مستويات -2 ,-1, 0, 1 ْم بالإضافة إلى استخدام نوعين من الأغلفة الصالحة للاكل وشملت ألجينات الصوديوم وشمع البرافين وتم اختبار كل من العاملين السابقين تحت نظام تبريد عادي يعتمد على نظام الثيرموستات الخاص بالثلاجة وآخر يتم التحكم فيه أوتوماتيكياً للابقاء على ثبات درجات الحرارة المطلوبة. تمت دراسة تأثير أغلفة ألجينات الصوديوم وأغلفة شمع البرافين على العمر الإفتراضى وخصائص جودة التفاح المخزن لمده 90 يوماً فى ظروف تبريد محكم وأظهرت المعاملات أعلى جودة ولون لثمار التفاح المغلف بغلاف ألجينات الصوديوم وشمع البرافين عند درجة حرارة صفر ْم ، ولوحظ ظهور العفن فى التفاح المغلف بألجينات الصوديوم عند درجة حرارة -2º م خلال فترة التخزين وزادت تلين الثمار مقارنة بدرجات الحرارة الأخرى. أظهرت النتائج أن التحكم في درجة الحرارة والابقاء على ثباتها طوال فترة التخزين أظهر تحسين لقدرة منظومة التبريد على الحفاظ على الخواص الكيميائية والفيزيائية للتفاح طوال فترة التخزين لجميع درجات الحرارة وخامات الأغلفة. أظهر التخزين تحت درجة حرارة صفرºم مع التغليف بشمع البرافين قدرة أفضل من باقي المعاملات للحفاظ على جودة التفاح المخزن من ناحية المحافظة على محتوى حامض الاسكوربيك، نسبة السكر، تخفيض فاقد الوزن، بالاضافة لتقييم اللون والطعم. على الجانب الأخر ظهرت أقل قدرة تخزينية تحت درجة حرارة -2ºم مع التغليف بالجينات الصوديوم والتي سجلت أعلى مؤشرات تدهور في صفات التفاح السابق ذكرها.

الكلمات المفتاحية: التفاح، الحفظ، الأغلفة الرقيقة، التخزين، التحكم الأوتوماتيكي، درجة الحرارة.

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