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RESEARCH ARTICLE

Sustainable edible coatings on physicochemical properties and storability of strawberry fruits

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Abstract

Despite of popularity for vibrant flavour and colour, strawberries rapidly lose commercial potential due to their delicate nature and high perishability, which poses a major hurdle for growers and retailers alike. Nowadays, fruit researchers are concerned about edible fruit coatings as a solution to this problem. In this present experiment, *Aloe vera* (L.) Burm.f. (AV) 60 %, sodium alginate (SA) 2 %, chitosan (C) 2 %, methyl cellulose (MC) 2 %, AV 60 % + C 2 %, AV 80 % + C 2 %, AV 60 % + ascorbic acid (AA) 2 %, C 2 % + AA 2 % edible coatings were applied on strawberry fruits alike other research. The treated and untreated fruits were maintained under room temperature and relative humidity (60 ± 5 °C). After fruit coating, observations were conducted at 0, 2 and 4 days. In comparison to all fruit coatings, SA 2 % was found to be most effective in preserving vitamin C, total sugar, reducing sugar, non-reducing sugar, titrable acidity, total antioxidant content, total anthocyanin content, total phenol content, total flavonoid content, as well as physiological weight loss (49.13), firmness, length, breadth and additionally increased pH. In conclusion, compared to other coated fruits and T9 (uncoated fruits), the SA 2 % (T4) coating was a most successful method for preserving the post-harvest quality of strawberry fruits under ambient conditions.

Keywords: *Aloe vera*; ascorbic acid; chitosan; methyl cellulose; sodium alginate; strawberry

Introduction

Non-climacteric strawberry (*Fragaria ananassa (*Duchesne ex Weston) Duchesne ex Rozier) belongs to the family Rosaceae, which is day-neutral, monoecious and the world's most popular fruit due to taste and nutritional qualities. Strawberry is also known as the "Queen of Fruits" (1). According to Indian Horticulture, the productivity of strawberries in India is approximately 20 t/ha (2). Majorly, strawberry fruits consist of water (91 %), carbohydrate (7.7 %) and a minor amount of fat (0.3 %) and protein (0.7 %) (3). Strawberries also contain vitamin C, antioxidants, polyphenols and amino acids, which minimise the risk of cancer, diabetes, stroke and heart disease. Strawberry fruits are consumed in huge quantities either fresh or processed as jam, juice, concentrate, candies, ice-cream, etc (4, 5). Crops start yielding during May–June, when strawberries are planted during September–October. This crop continues to yield up to the 3rd year of planting, which is 8 t/acre (6).

Most physical treatments have harmful effects on nutritional and taste components; therefore, novel methods should be investigated and applied to address these problems. Second-generation edible coating materials can prevent microbial growth and oxidation on fruits with chemicals, enzymes and microorganisms. Several investigations demonstrated that essential oils with polymers are potential sources of edible coating, having efficiency of antimicrobial and antioxidant properties (7). Post-harvest life of the strawberry is very short due to quick metabolism and susceptibility to mechanical damage and phytopathogenic microbes (8). Perishability, fast respiration, fragile texture and temperature sensitivity make them subject to mechanical injury, physiological weight loss and decay (9). Before reaching consumers, fruit and vegetable postharvest losses in the supply chain are 13 %–38 %. Strawberries are harvested at the ripe stage and they are attacked by microorganisms due to their soft tissues. They are easily desiccated due to high respiration and transpiration rate and susceptible during handling, transportation and storage (9).

Utilization of edible coatings made from natural polymers like chitosan, sodium alginate, waxes has diversified effects on postharvest qualities of fruits. To maximize the advantages of edible coatings on strawberry fruits, proper handling, storage temperature and postharvest management practices are necessary (10). Different measures were taken to prevent post-harvest losses and increase shelf life of fruits. Fruit preservation uses physio-biochemical approaches. Temperature, humidity and gas composition are regulated to improve shelf life by controlled environments (11). In recent time, food industries are concerning about the potential approaches of edible coating. Protective barriers formed by coating reduce moisture loss, lower microbial development and maintain the freshness, flavour and appearance of strawberry fruits. Effective transportation and marketability can be increased by novel coating which will reduces the fruit waste (12).

Few recent studies conducted on coatings are yam and corn starch on Rio Grande Cherry (13), Chitosan (14), coconut oil with cassava starch (15) and *Aloe vera* (L.) Burm.f. (16). Therefore, this research was conducted to investigate the impact of different combinations of coating materials and compare the context of TSS, titrable acidity, total sugar, reducing sugar, non-reducing sugar, physiological weight loss, length, breadth, firmness, total phenol, total flavonoid, antioxidant content, total anthocyanin content and pH. To improve the postharvest qualities of strawberry fruits, the present investigation was conducted to evaluate the effect of edible coating on physicochemical properties.

Materials and Methods

Experimental details

The present investigation was conducted at the postharvest laboratory, Department of Horticulture, Lovely Professional University. From Ludhiana farm, fresh, physiologically matured and disease-free strawberry fruits were collected for the experiment during the month of February. Then, fruits were brought the laboratory of Lovely Professional University in punnet boxes to avoid quality deterioration. After that fruits were cleaned with 0.01 % chlorinated water and allowed to air dry for an hr in room temperature. The 9 treatments were T1: Aloe vera (AV) (60 %),T2: AV (60 %) + Chitosan (C) (2 %), T3: AV (80 %) + C (2 %), T4: sodium alginate (SA) 2 %, T5: C 2 %, T6: AV (60 %) + ascorbic acid (AA) (2 %), T7: C (2 %) + AA (2 %),T8: methyl cellulose (MC) (2 %) and T9: control. The physicochemical observations were taken and a statistical analysis was done based on the CRD design.

Coating material preparation and application

A chitosan solution was prepared with 100 mL of 2 % of C formulations. Dissolving 2 g of C in 75 mL of distilled water and addition of 2 mL of glacial acetic acid. Stir the mixture constantly and heat it to 55 ºC with a shear rate of 8.33 s^{-1} to make sure that chitosan is fully dissolved. Adjust the solution pH to 5.6 by using 2 N NAOH and the final volume brought up to 100 mL with sterilized distilled water (9). AV coating was prepared using mature leaves of *Aloe vera* and cleaned with a 25 % chlorine solution. The inner gel matrix was extracted by removing the outer cortex of leaves. The hydro parenchymatous tissue was blended to make it smooth and then filtered to eliminate fibrous material. The resulting gel is heated to 70 ºC for 45 min and then cooled down to room temperature. The final pH was adjusted to 4.0 (9). MC coating was prepared by dissolving 2 g of MC powder in 100 mL of a mix of water and ethyl alcohol at 75 ºC with magnetic stirring of 15 min. Ethyl alcohol helps to make coating dry faster and produce clear, glossy MC coating. Add glycerol (1.9 g/100 g) and the mixture. Continue stirring for another 10 min under the same heating conditions and then let it cool down (17). SA coating was prepared by dissolving 4 g of SA powder in 200 mL of water with continuously stirring. A 2 % SA was achieved by gradually adding the powder by stirring magnetically at 80 ºC until it was fully dissolved (18). AA coating was prepared by dissolving 1 g of AA in 100 mL of warm distilled water (19). After coating the samples, they are shed dried.

Assessment of physiological attributes

Before coating, the initial fresh fruit weight was taken, then 0, 2 and 4 days after coating fruit weights were taken. Based on initial weight, the physiological loss in weight (PLW) in percentage was calculated at the end of each storage interval by initial weight of fruits minus final weight of fruit divided by initial weight of fruits (20). From top to bottom of the fruits, length was measured at the initial stage and at all the stages after coating with a vernier calliper (21). At the thickest part of the fruit, from one side to another side, the breadth was measured with the help of a vernier calliper (21). With the help of a 5 mm flat probe, the firmness of the strawberry fruit was measured. The maximum penetration force (N) during tissue breakage was measured as a measure of firmness (21).

Assessment of bio-chemical attributes

Total soluble solids (TSS) are expressed in °Brix and measured using a digital refractometer (10). 20 g of strawberry homogenised fruit pulp was mixed with 80 mL of distilled water and the pH meter was used to measure the pH of the solution. Standard solutions were taken for calibration of the pH meter (10). The total sugar content was estimated using volumetric method (22). The reducing sugar content (%) was also estimated (22). 2 g of fruit pulp made up to 50 mL solution by adding distilled water, then 2 mL of lead acetate (45 %) was added to it and stand for 10 min. Then the solution was filtered and 25 mL sample was taken and titrated with 5 mL of Fehling solution A and B and methylene blue indicator until brick red colour. Non-reducing sugar (%) calculated by subtracting reducing sugar from total sugar (22).Vitamin C (mg/100 g) content of fruit involves blending fruit sample with a weak acid solution, then filter the solution and analyse the filtrate using UV-VIS spectrophotometer (23). Titrable acidity (%) content was estimated by titrating a diluted fruit sample with standardized base (0.1 N sodium hydroxide) using phenolphthalein as indicator (22). Total flavonoid (mg/100 g) content of strawberry fruit involves use a combination of extraction and colorimetric analysis (23). Total phenols (mg/100 g) extraction relies on the reducing capacity of phenolic compounds that react with Folin-Ciocalteu reagent and a base (sodium carbonate) leading to a colour change which can be measured by spectrophotometrically. The measured absorbance is correlated to a standard curve of a known phenolic compound (gallic acid), which will quantify the total phenol content (24, 25). To determine the total antioxidant activity (%) of strawberry fruits, spectrophotometric assays (DPPH) was used (26). Anthocyanin content (mg/100 g) methods involve solid-liquid extraction using solvent (ethanol) followed by quantification using spectrophotometry (19). For the statistical analysis, completely randomized design (CRD) was used with 9 treatments and 3 replications. ANOVA at the CD level of 0.05 % used to analyse the collected data to determine significant differences between treatments and the statistical analysis of the data has been done by using Microsoft excel and OPSTAT software (27).

Result and Discussion

Physiological parameters

The data on the effect of different coating material on physiological loss in weight (%) of strawberry fruits is presented in Table 1. There was a significant difference between the treatments and PLW (%) increases with the days progresses after coating. On the 2nd and 4th days after coating on strawberry fruits, T4 showed the minimum physiological loss in weight followed by 5 as compared to the uncoated fruits (T9) as maximum PLW (%). The

Table 1. Effects of different edible coatings on PLW (%) of the strawberry fruit

Treatments	0 DAC	2 DAC	4 DAC
T1	0.00	26.20	63.33
T2	0.00	24.60	61.07
T3	0.00	27.10	63.47
T4	0.00	18.50	49.13
T5	0.00	22.20	53.60
T6	0.00	27.80	59.00
T7	0.00	26.80	64.60
T8	0.00	25.30	63.80
T9	0.00	31.20	75.77
C.D.	N/A	0.422	1.712
S.E (m) ±	0	0.141	0.572

same outcomes also observed in strawberry (28, 29), Litchi (30), apricot (31) and peach (32). After harvesting, increasing transpiration and respiration causes physiological loss in weight. During transpiration, moisture losses through fruit surface by lenticels and stomata. During respiration, stored food material in fruits breaks into water and carbon dioxide. Transpiration and respiration rate is less in coated fruits due to anti-senescence layer formed by coating material, which prevent ethylene biosynthesis and enzymatic action slows down (33, 34).

The effect of edible coating material on the length (cm) of strawberry fruits is presented in Table 2. Treatment T4 shows the minimum loss of length, followed by T5 on the 2nd and 4th days after coating, as compared to T9, which shows the maximum loss in length. The similar results were also observed in olive (35) and in Ber (36). The reduction in fruit length was caused by shrinkage due to transpiration and respiration. Anti-senescence effect of edible coating material on strawberry fruits inhibits ethylene biosynthesis and retard ripening enzyme activity (34, 35).

The data presented in Table 3 shows the effect of edible coating on the breadth (cm) of strawberry fruit crops. The minimum loss in breadth was observed in treatment T4, followed by T5, compared to uncoated fruits (T9) at the 2nd and 4th days after coating. Observations in Olive (35) and in Ber (36) were the same. Cell degradation of the strawberry fruit occurs due to ethylene biosynthesis and the activity of enzymes responsible for ripening, which results in shrinkage and is caused by transpiration and respiration after fruit harvesting at room temperature. Fruits coated with edible coating, especially T4 and T5, restrict and slow down the transpiration and respiration rate of fruits, as well as the shrinkage (34, 35).

Effects of different edible coating materials on firmness (cm) of strawberry fruits are presented in Table 4. On the 2nd day after coating, the strawberry fruits treated with T4 showed maximum firmness, followed by T2, T5 and T9, as compared to T3 and T6,

Table 2. Effects of different edible coating on length (cm) of strawberry fruit

Treatments	0 DAC	2 DAC	4 DAC
T1	4.44	4.08	3.54
T2	4.42	4.09	3.63
T3	4.44	4.10	3.66
T4	4.44	4.25	3.92
T5	4.43	4.19	3.84
T6	4.42	4.10	3.63
T7	4.44	4.08	3.65
T8	4.42	4.09	3.68
T9	4.43	3.90	3.45
C.D.	N/A	0.096	0.139
S.E (m) ±	0.01	0.032	0.047

Table 3. Effects of different edible coating on breath (cm) of strawberry fruit

Treatments	0 DAC	2 DAC	4 DAC
T1	3.14	2.81	2.55
T2	3.13	2.81	2.61
T3	3.14	2.82	2.56
T4	3.14	2.93	2.79
T5	3.13	2.88	2.75
T6	3.13	2.79	2.60
T7	3.13	2.81	2.62
T8	3.14	2.84	2.63
T9	3.14	2.70	2.42
C.D.	N/A	0.113	0.118
S.E (m) ±	0.007	0.038	0.039

Table 4. Effects of different edible coating on firmness (N) of strawberry fruit

Treatments	0 DAC	2 DAC	4 DAC
T1	4.54	3.69	2.28
T2	4.55	3.66	2.28
T3	4.53	3.68	2.24
T4	4.56	4.13	2.69
T5	4.55	3.90	2.60
T6	4.53	3.68	2.29
T7	4.54	3.70	2.29
T8	4.54	3.67	2.23
T9	4.55	3.54	1.85
C.D.	0.22	0.222	0.192
S.E (m) ±	0.007	0.074	0.064

which showed minimum firmness. On the 4th day after coating, T4 showed the highest firmness, followed by T5, as compared to T9, which showed the lowest firmness. Similar studies were also conducted in strawberry fruit (18). With the change in cell wall structure, fruit tissues softening occurs. Simultaneously, the biochemical processes involve pectin and starch hydrolysis by enzymes with wall hydrolysis. Depolymerisation (chain length of pectin substances shortens) during fruit ripening occurs due to increasing pectin esterase and polygalacturonate activities (37).

Bio-chemical parameters

The effect of edible coating on total soluble solids (TSS) of strawberry fruits is presented in the table 5. Treatment T8 shows the highest TSS, followed by T1, T4, T6 and T9 on the day of coating, compared to T2 and T7, which show the lowest TSS. On the 2nd and 4th days after coating, T4 showed the highest TSS, followed by T5, as compared to T9 (uncoated fruits), which shows the lowest TSS. Similar results were shown in strawberry (18, 38). With the reduction in moisture, the soluble solids concentration also reduces, which is linked with the TSS content of the strawberry fruits. With the progression of ripening, complex carbohydrates break down into soluble solids and respiration rate increases. Amylases, starch phosphorylases, 1,6-glucosidase enzymes together break down starch into sugars lie sucrose, glucose and fructose (11).

In Table 6, the effect of edible coating material on titrable acidity (%) are presented. On the day of coating, strawberry fruits coated with T4 show maximum TA content as compared to the uncoated fruits, which show minimum TA content. On the 2nd and 4th days after fruit coating, T4 shows the highest TA content, followed by T5, as compared to T9 (uncoated fruits), which contains the lowest TA. Similar results were observed in strawberries (18), in avocados and peaches (32, 39). After harvesting of strawberry fruits, the organic acids reduce by the respiration process and organic acid has direct impact on titrable acidity content of fruits (32).

The effects of edible coating on the vitamin C (mg/100 g) of fruits presented in the Table 7. There was a significant variation of vitamin C content between the treatments. On the day of coating, T4 shows the highest vitamin C content followed by T8 as compared to the uncoated fruits which shows minimum vitamin C content. On the 2nd and 4th days after coating, T4 shows minimum loss of vitamin C followed by T5 as compared to T9 (uncoated fruits) which shows maximum loss of vitamin C. similar results were observed in avocado (39) and in olive (35). During fruit processing and storage, ascorbic acid is most sensitive to degradation due to its oxidation as compared to other nutrient content of the fruits (40).

Table 8 presenting the data of the effects of coating material on the total sugar (%) of strawberry fruits. On the day of coating, T7 shows the highest total sugar content followed by T4, T2, T8 and T9 as compared to T3 and T1 which shows lowest total sugar content. On the 2nd and 4th days after coating, T4 shows maximum total sugar content followed by T5 as compared to uncoated fruits which shows minimum total sugar content. Similar results were observed in Ber (41) and in apricot (42). During the storage period, fruit ripening starts with an increase in sugar level in the strawberry fruit. At the initial stages, the fruit sugar level is less. But with increasing storage days, AA content increases and after some days it gets reduced (41).

Table 5. Effects of different edible coating on TSS (°Brix) of strawberry fruit

Treatments	0 DAC	2 DAC	4 DAC
T1	6.95	7.74	7.36
T2	6.93	7.85	7.43
T3	6.93	7.83	7.50
T4	6.95	8.26	7.76
T5	6.94	8.11	7.71
T6	6.95	7.78	7.48
T7	6.93	7.91	7.49
T8	6.96	7.86	7.24
T9	6.95	7.67	6.90
C.D.	N/A	0.260	0.106
S.E (m) ±	0.01	0.087	0.035

Table 6. Effects of different edible coating on titratable acidity (%) of strawberry fruit

Treatments	0 DAC	2 DAC	4 DAC
T1	1.23	0.75	0.33
T2	1.23	0.70	0.34
T3	1.22	0.70	0.36
T4	1.25	0.80	0.39
T5	1.23	0.78	0.37
T6	1.22	0.67	0.36
T7	1.23	0.70	0.34
T8	1.23	0.70	0.35
T9	1.23	0.59	0.30
C.D.	N/A	0.089	0.024
S.E (m) ±	0.006	0.030	0.008

Table 7. Effects of different edible coating on vitamin C (mg/100 g) of strawberry fruit

Treatments	0 DAC	2 DAC	4 DAC
T1	35.53	30.30	23.23
T2	35.17	30.47	23.40
T3	35.23	29.80	23.60
T4	35.97	32.97	26.90
T5	35.50	31.90	24.30
T6	34.40	30.43	23.47
T7	34.20	29.07	22.50
T8	35.60	29.37	22.27
T9	35.10	28.67	19.37
C.D.	N/A	1.829	0.663
S.E (m) ±	0.486	0.611	0.221

Table 8. Effects of different edible coating on total sugar (%) of strawberry fruit

Treatments	0 DAC	2 DAC	4 DAC
T1	5.52	6.64	6.28
T2	5.53	6.62	6.29
T3	5.51	6.67	6.21
T4	5.53	6.86	6.44
T5	5.51	6.73	6.39
T6	5.52	6.63	6.18
T7	5.54	6.65	6.10
T8	5.53	6.66	6.20
T9	5.53	6.48	6.08
C.D.	N/A	0.128	0.106
S.E (m) ±	0.008	0.043	0.035

The data on the effect of edible coating material on reducing sugar (%) is presented in Table 9. In respect to reducing sugar content in fruits, significant variations in the data are visible. On the day of coating, T4 and T1 show the highest reducing sugar content as compared to T9, which shows the minimum reducing sugar content. On the 2nd and 4th days after coating, maximum reducing sugar content was shown by T4 followed by T5 as compared to uncoated fruits which contains minimum reducing sugar. Similar results were observed in carambola (43). Enzymatic conversion of starch to reducing sugar is correlated to increase in reducing sugar content (43, 44).

Data presented in Table 10 shows the effect of different types of edible coating on the non-reducing sugar (%) content of strawberry fruits, which shows significant variations in the treatments. On the day of coating, T8 and T9 shows maximum no-reducing sugar content as compared to T3 which shows minimum no-reducing sugar content. On the 2nd and 4th days after coating, T4 shows highest non-reducing sugar content followed by T5 as compared to T9 (uncoated fruits) which shows minimum non-reducing sugar content. Similar results were observed in carambola (43). There is a direct correlation between enzymatic conversion of starch and increase in non-reducing sugar content. After harvesting of strawberry fruits, with the increasing rate of respiration enzymatic conversion of starch into reducing sugar increases. Then after some days again the no-reducing sugar content reduces because less starch left for conversion into non-reducing sugar (43).

The effect of edible coating on the total phenol (mg/100 g) content in strawberry fruits are presented in the Table 11. On the day of coating, T4 shows maximum total phenol content followed by T9 as compared to minimum total phenol content showed by T3. 2nd and 4th days after fruit coating, T4 shows highest total phenol content followed by T5 as compared to uncoated fruits (T9) which shows minimum total phenol content. Similar results were

Table 9. Effects of different edible coating on reducing sugar (%) of strawberry fruit

Treatments	0 DAC	2 DAC	4 DAC
T1	2.27	2.84	2.72
T2	2.25	2.90	2.75
T3	2.26	2.80	2.66
T4	2.27	2.66	2.52
T5	2.26	2.78	2.57
T6	2.25	2.89	2.73
T7	2.26	2.81	2.72
T8	2.23	2.80	2.70
T9	2.23	3.09	2.64
C.D.	N/A	0.123	0.145
S.E (m) ±	0.011	0.041	0.048

Table 10. Effects of different edible coating on non-reducing sugar (%) of strawberry fruit

Treatments	0 DAC	2 DAC	4 DAC
T1	3.09	3.61	3.38
T2	3.12	3.53	3.36
T3	3.08	3.67	3.37
T4	3.10	3.98	3.73
T5	3.09	3.75	3.63
T6	3.11	3.55	3.28
T7	3.12	3.65	3.21
T8	3.13	3.67	3.32
T9	3.13	3.22	3.27
C.D.	N/A	0.162	0.159
S.E (m) ±	0.015	0.054	0.053

Table 11. Effects of different edible coating on total phenols (mg/100 g) of strawberry fruit

Treatments	0 DAC	2 DAC	4 DAC
T1	182.50	94.67	63.40
T2	182.50	97.57	64.20
T3	181.37	93.73	68.73
T4	184.90	104.47	87.90
T5	183.00	100.23	78.30
T6	182.87	92.07	61.07
T7	183.60	92.03	60.53
T8	183.40	95.00	60.77
T9	184.03	87.40	30.23
C.D.	1.865	1.387	1.927
S.E (m) ±	0.623	0.463	0.644

also observed in strawberry fruits (11, 45). After fruit harvesting, as ripening progresses, secondary metabolites are produced by synthesising phenolic compounds (46). Loss of antioxidant activity is correlated with loss of total phenol content of the fruits (28).

Table 12 represents the significant variations in the treatments of the effects of edible coatings on the total flavonoids (mg/100 g) content of strawberry fruits. On the day of coating, T4 shows the highest total flavonoid content, followed by T5, as compared to T6, which shows the lowest total flavonoid content. On the 2nd day after coating, T4 shows the minimum loss of total flavonoids, followed by T5, as compared to the maximum loss of total flavonoids. On the 4th day after coating, treatment T4 shows minimum loss of total flavonoid content, followed by T5, as compared to maximum loss of total flavonoid content in uncoated fruits. Similar result was observed in strawberry fruits (45). During storage, the total flavonoid content reduces as the day progresses, because the presence of glycosides attached to flavonoid aglycons (flavanol or anthocyanin) decreases the antioxidant activity of flavonoids (12).

The data presented in Table 13 shows the effect of edible coatings on the total antioxidant activity (%) of strawberry fruits, which represents the significant variations between all the treatments. On the day of coating, T5 treatment shows the highest total antioxidant activity, followed by T1, as compared to T8 and T6, which show the lowest antioxidant activity. On the 2nd and 4th days after coating, T4 shows maximum antioxidant activity, followed by T5, as compared to T9, which shows minimum antioxidant activity. Same results were also observed by the previous researchers (28, 45, 47, 48). As the days progresses after harvesting, strawberry fruit sugar contents also reduce with higher rate of respiration. During that process the total antioxidant activity of the fruits also decreases with the simultaneous reduction of total phenol content, total anthocyanin content and total flavonoid content (28, 49).

The effect of edible coating on the total anthocyanin content (mg/100 g) of strawberry fruits are presented in the Table 14. On the day of fruit coating application, T1 shows highest anthocyanin content followed by T4 as compared to the lowest anthocyanin content by T9. On the 2nd and 4th days after coating, T4 shows maximum anthocyanin content followed by T5 as compared to the minimum anthocyanin content by T9. Similar results were observed previously (28). With increasing storage days after coating, there is a positive correlation between total antioxidant activity and total anthocyanin content. With the reduction of antioxidant activity, total anthocyanin and total phenol content is also reduced more in uncoated fruits and comparatively less in coated strawberry fruits (28).

Table 15 presents the data on the effect of edible coating material on the pH of strawberry fruits. Significant variations of treatments are visible in the table. On the day of coating, T4 shows the highest pH as compared to the fruits of T6 and T9, which show the lowest pH. On the 2nd and 4th days after coating, T4 shows maximum pH followed by T5 as compared to minimum pH by the uncoated fruits. Similar observations are followed by earlier researchers in strawberry fruits (18). During fruit storage, the rate of respiration of the strawberry fruits increases the

Table 12. Effects of different edible coating on flavonoids (mg/100 g) of strawberry fruit

Treatments	0 DAC	2 DAC	4 DAC
T1	147.31	80.19	69.99
T2	144.83	82.71	71.17
T3	145.75	88.03	70.93
T4	161.25	101.24	88.32
T5	153.61	96.57	82.67
T6	144.57	83.75	70.29
T7	147.77	82.20	72.82
T8	145.92	82.61	71.67
T9	146.74	73.77	59.64
C.D.	N/A	2.569	2.090
S.E (m) ±	4.687	0.858	0.698

Table 13. Effects of different edible coating on total antioxidants activity (%) of strawberry fruit

Treatments	0 DAC	2 DAC	4 DAC
T1	30.24	26.13	19.76
T2	30.11	25.25	19.99
T3	30.18	23.28	18.80
T4	30.11	28.14	23.79
T5	30.31	26.77	21.81
T6	30.10	23.71	19.94
T7	30.31	23.54	18.82
T8	30.10	23.65	19.70
T9	30.13	23.39	17.43
C.D.	N/A	2.246	1.14
S.E (m) ±	0.100	0.75	0.381

Table 14. Effects of different edible coating on anthocyanin (mg/100 g) of strawberry fruit

Treatments	0 DAC	2 DAC	4 DAC
T1	35.03	31.31	27.09
T2	34.62	30.97	27.18
T3	33.78	30.38	27.15
T4	34.94	32.23	29.49
T5	33.61	31.36	28.13
T6	33.42	29.42	26.48
T7	34.34	30.61	26.84
T8	34.27	31.00	27.16
T9	31.50	27.57	25.68
C.D.	N/A	1.392	1.159
S.E (m) ±	0.856	0.465	0.387

Table 15. Effects of different edible coating on pH of strawberry fruit

Treatments	0 DAC	2 DAC	4 DAC
T1	3.62	3.73	3.74
T2	3.64	3.73	3.73
T3	3.60	3.86	3.86
T4	3.68	3.98	4.14
T5	3.64	3.80	3.87
T6	3.61	3.72	3.78
T7	3.63	3.74	3.80
T8	3.64	3.76	3.83
T9	3.61	3.65	3.67
C.D.	N/A	0.092	0.074
S.E (m) ±	0.016	0.031	0.025

sugar content by decreasing (enzymatic activity) the organic acid content of the fruit. This directly effects on the pH of edible coated fruits that increases with the ripening process, which prevent mould formation and delay in ripening (18).

Sustainable edible coating often enriched with natural antimicrobials and antioxidants that are effective to slow physicochemical deterioration and strawberry storability. Coating materials form semipermeable barriers that reduce transpiration and gas exchange, which lowers weight loss and higher firmness (50, 51). Beyond moisture control, edible coatings help to preserve quality matrices like, slow decline in titrable acidity and vitamin C, stabilize total soluble solid/TA ratio, total anthocyanin, flavonoids which preserves colour and antioxidant capacity, reducing microbial spoilage and delaying senescence (51).

Conclusion

Strawberry fruits are highly perishable due to high moisture content and metabolic activity. Sustainable approach to extend the shelf life of strawberry fruit is edible coatings which provide a barrier to protects the strawberry fruits from the adverse effects of environments causing physiological and bio-chemical changes in fruits. From different treatments, SA 2 % was the most effective coating material which extending the shelf life of strawberry fruits for 4 days after harvesting. SA 2 % significantly reducing physiological loss in weight and reducing sugar with maintaining higher levels of total soluble solids, total sugar, total anthocyanin, total flavonoid, total antioxidant activity, firmness, titrable acidity and pH. This experiment clearly demonstrates that the eco-friendly edible coating act as a semi-permeable barrier, modulating gas exchange and moisture loss, while preserving, texture, colour, flavour and nutritional quality. Future focuses on continuation to this present experiment will be nano-reinforcement of antimicrobial and antioxidant materials, mathematical modelling of moisture and gas permeability, scaling-up the method, consumer acceptability, benefit-cost ratio etc.

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Authors' contributions

RM planned the entire experimental design and guided ST to conduct the entire research work. RM, B, NY and MT wrote the article. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

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