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Inhibition of browning in fresh-cut apple wedges through edible coatings and anti-browning agents

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ABSTRACT

The consumption of minimally processed apples has grown rapidly due to increasing willingness of consumers to enjoy ready-to-eat cut fruits. The minimally processed apples, however, tend to experience severe browning and lowers its acceptability. In the present work, carboxymethyl cellulose (CMC) and *Aloe vera* coating containing 4-HR, ascorbic acid (AA), calcium chloride and cysteine were applied alone and/or in combination on minimally processed apple wedges to evaluate their preservative effects. Physico-chemical quality was evaluated during 7 days of storage at 5 ± 2ºC. Anti-browning dip treatment combined with edible coatings prevented loss of colour during the 7 days of storage. The treatment inhibited browning, retained colour and decreased CO_2 production and O_2 consumption, total soluble solid (TSS) content and titratable acidity (TA) of the apple wedges. Browning incidence with carboxymethyl cellulose (CMC) and *Aloe vera* in combination with anti-browning agents was lower than when they were used alone. L* index was higher for treated wedges than that of uncoated wedges throughout storage period. These findings suggest that the combined use of anti-browning agents and CMC may be useful for preserving quality and reducing browning of minimally processed apple wedges.

Keywords: *Malus × domestica*, edible coatings, anti-browning, *Aloe vera* coating, carboxymethyl cellulose.

INTRODUCTION

Apple fruit helps improving people's health because of its nutritional vitamins and phenolic compounds (Biedrzycka and Amarowicz, 2). Recently, fresh-cut apple wedges have emerged popular in food service establishments and social gatherings because they provide convenience to consumers. But a major constraint is its susceptibility to enzymatic browning that leads to loss of colour and thereby major factor of deteriorating quality and discouraging consumers to buy minimally processed apple wedges (Lu *et al.,* 6). Thus, a need is felt to develop appropriate methods to minimize the deterioration of apple wedges and extend their storage life.

Strategies for extension of shelf life of minimally processed fruits include packaging and processing technologies. Among packaging technologies, modified atmospheric packaging with suitable packaging materials have been widely adopted to slow down the produce metabolism (Rocculi *et al.,* 10). Various innovations are available today for limiting the quality loss, such as the use of non-thermal technologies (Moreira *et al.,* 7) and edible coatings (Kumar *et al.*, 5). The application of edible coatings on fresh produce can minimize quantity losses and quality changes through modification and controlling internal gaseous composition of individual fruit (Kumar *et al.*, 5). Edible coatings are also useful as carriers of food additives involving browning inhibitors and antioxidants (Dhall, 4). Therefore, many researchers have been studying the potential of various coating materials on maintaining the quality and increasing the storage life of minimally processed fruits. Coatings can be prepared from proteins, polysaccharides, lipids or the combination of these components. Among them, CMC, a linear, long-chain, water soluble, anionic polysaccharide is being used widely as a fruit coating. Saba and Sogvar (11) reported that CMC coating in combination with browning inhibitors (calcium chloride and ascorbic acid) effectively inhibits the browning and maintains quality of fresh-cut apples. Aloe vera based coatings have been shown to decrease loss of moisture and fruit firmness, control respiration, delay oxidative browning and prevent growth of microorganisms in fruits (Ahmed *et al.,* 1).

Until recently, there have been few researches that investigated the effect of the combination of CMC, aloe vera and anti-browning agents for fresh-cut products to inhibit browning. The objectives of the work were to extend the shelf life of fresh-cut 'Royal Delicious' apple wedges under the influence of CMC and *Aloe vera* in combination with anti-browning agents by inhibiting enzymatic browning.

MATERIALS AND METHODS

Royal Delicious apples were procured from Seobagh, Kullu, Himachal Pradesh at appropriate

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stage of maturity. Apples with uniform size were rinsed in tap water and cut into eight equal wedges using a manual apple slicer followed by treatment with anti-browning agents and edible coatings alone as well as in combination. Chemicals used for the study were procured from Sigma, Merck and SRL Technologies, India.

Aloe vera leaves were washed and peeled. The transparent pulp obtained was homogenized and filtered through a muslin cloth. The pure aloe vera homogenates were diluted with distilled water to get a concentration of 15%. CMC coating (1%) was prepared by dissolving 1 g carboxymethyl cellulose in 100 mL distilled water (DW) at 75°C under magnetic stirring for 30 min.

Fresh-cut apple wedges were divided in twelve groups and were dipped in the following solutions for 5 minutes: T_0: distilled water (DW) as control, T_1: ascorbic acid (1%) + $CaCl_2$ (1%), T_2: 4-hexylresorcinol (0.01%) + ascorbic acid (0.5%) + $CaCl_2$ (0.2%), T_3: cysteine (0.1%), T_4: aloe vera gel (15%), T_5: aloe vera (15%) + 4-hexylresorcinol (0.01%) + ascorbic acid (0.5%) + $CaCl_2$ (0.2%), T_6: aloe vera (15%) + ascorbic acid (1%) + $CaCl_2$ (1%), T_7: aloe vera (15%) + cysteine (0.1%), T_8: carboxymethyl cellulose (1%), T_9: CMC (1%) + 4-hexylresorcinol (0.01%) + ascorbic acid (0.5%) + $CaCl_2$ (0.2%), T_{10}: CMC (1%) + ascorbic acid (1%) + $CaCl_2$ (1%) and T_{11}: CMC (1%) + cysteine (0.1%). The excess of solution was drained off followed by air-drying. Wedges were packaged in polypropylene boxes, shrink wrapped and stored at 5± 2°C in cold chamber. In cold chamber the apple wedges were analyzed every day for a period of seven days for different quality attributes: Flesh colour was determined using portable colorTec PCM (USA). Measurements were made just immediately after the apple slices were treated and at every day thereafter. The colour value was expressed as chroma and hue index by using corresponding L^*, a^* and b^* values. The carbon dioxide (CO_2) and oxygen (O_2) levels inside containers during storage were recorded with a check point O_2 / CO_2 (Model: Checkmate 9900 O_2/CO_2, PBI Dansensor, Denmark). Attributes were expressed as ΔCO_2 and ΔO_2 percentage with reference to initial values. Browning potential (BP) and degree of inhibition in fresh-cut apple wedges was determined according to the method of Chiabrando and Giacalone (3). Ten gram apple wedges from each treatment were homogenized, the homogenates were centrifuged at 10000 rpm for 10 min, and the aliquot was filtered through filter paper. The absorbance of the clear aliquot was then measured spectrophotometrically at 440 nm to determine potential browning. The total soluble solid (TSS) content of samples was estimated using hand refractometer (0-50ºB, ATAGO make) and expressed as degree Brix (ºB) at 20ºC. Titratable acidity (TA) of the apple samples was determined as per the standard procedure of Ranganna (9).

Two way analysis of variance was performed on the data sets using SAS 9.3 software and significant effects ($p< 0.05$) were noted. Significant difference amongst the means was determined by Tukey's HSD. This measurement was replicated three times.

RESULTS AND DISCUSSION

Respiration in apples involved a continuous decrease in oxygen and increase in carbon dioxide as storage period progressed. Production of undesirable gas concentrations during storage accelerates the ripening and enhances microbial spoilage. As shown in Figs. 1 and 2, edible coatings with anti-browning agents exhibited lower O_2 consumption and CO_2 production while the untreated apple wedges showed highest O_2 consumption and CO_2 production during storage. As far as the changes in ΔCO_2 and ΔO_2 is concerned, it was observed that apple wedges dipped in CMC containing 4-HR, AA, $CaCl_2$ showed the lowest CO_2 production and O_2 consumption during storage whereas only cysteine treatment resulted in highest CO_2 production and O_2 consumption as a result of greater metabolic changes. Similar trend of reduction of ΔO_2 and increase of ΔCO_2 levels in apple slices has been reported previously also (Rocculi *et al.,* 10).

Fig. 3, shows data corresponding to the browning potential (BP) of the control and treated samples. Apple wedges treated with edible coatings and browning inhibitors alone or in combination had the lowest BP during the storage of 7 days. At the end of storage, the lowest BP was observed in apple wedges treated with CMC and *Aloe vera* in combination with 4-HR, AA, $CaCl_2$ and the highest for control (water dipped) apple wedges.

Higher inhibition degree was found for anti-browning agents with edible coatings in combinations. On the contrary, apple wedges treated with edible coatings and anti-browning agents alone showed the lowest inhibition degree. These results were in agreement with Chiabrando and Giacalone (3) where they studied the effect of ascorbic acid and calcium chloride, citric acid and calcium chloride and 1-MCP for fresh-cut apples.

The colour changes in minimally processed fruits have been broadly reported by many researchers (Yan *et al.,* 12; Zuo *et al.*, 13) and in fresh-cut fruits the browning mainly considered as the limiting factor for the storage life. Polyphenol oxidase enzyme is the key enzyme responsible for oxidative browning in the presence of O_2 that converts the phenolic

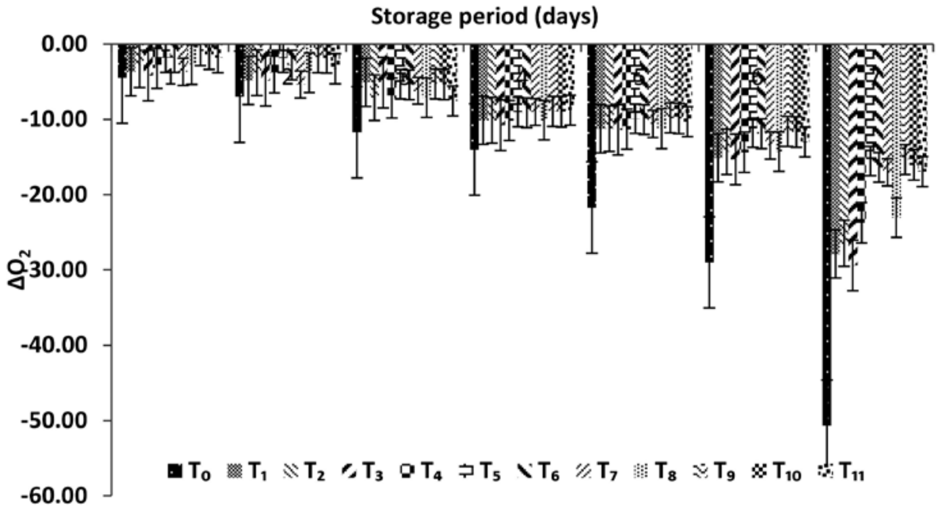

Fig. 1. Effect of edible coatings and anti-browning agents on ΔO_2 of fresh-cut apple wedges under low temperature storage.

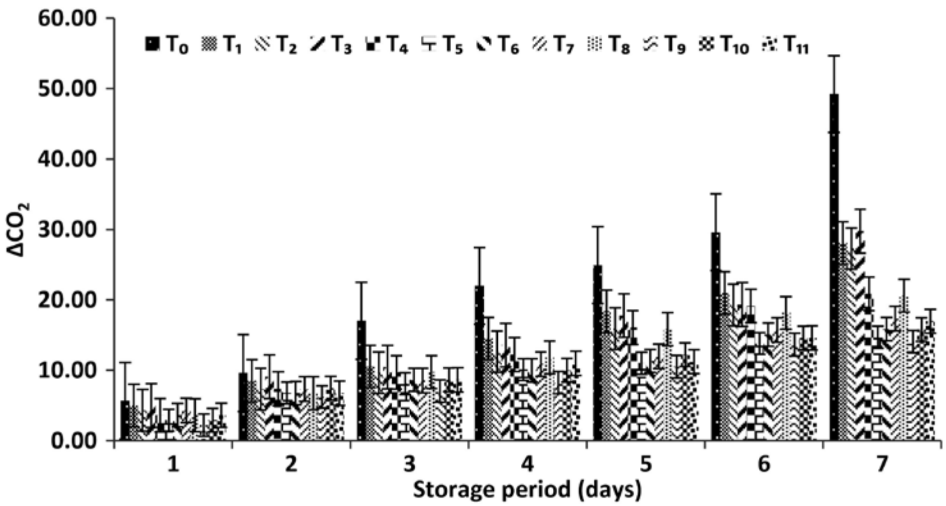

Fig. 2. Effect of edible coatings and anti-browning agents on ΔCO_2 of fresh-cut apple wedges under low temperature storage.

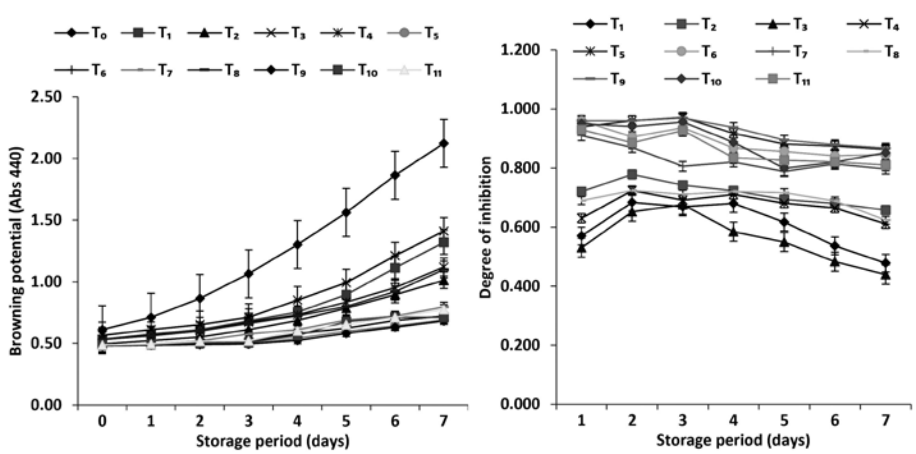

Fig. 3. Effect of edible coatings and anti-browning agents on browning potential and degree of inhibition of fresh-cut apple wedges under low temperature storage.

compounds into dark brown coloured pigments. During the storage duration of 7 days, chroma of the apple wedges in the combined anti-browning and edible coatings treatment groups were lower than for sole anti-browning and coatings treatment (Table 1). The results suggest that the coatings (CMC and *Aloe vera*) in combination with browning inhibitors can effectively control discolouration in apple wedges. The samples treated with combination of CMC, 4-HR, AA, $CaCl_2$ (T_9) showed least changes (~47% lower in comparison to control) in chroma during storage. Chroma of T_1, T_9 and T_5 samples were 28.93, 15.31 and 16.57, respectively on 7th day at 5 ± 2°C. The apple wedges treated with anti-browning agents alone and in combinations with edible coatings maintained lower reduction in hue angle than control throughout the storage period (Table 1). The hue values of control decreased remarkably than those of other treatments, with a hue of 81.87 after 7 days of storage. Treatment of apple wedges with CMC containing 4-HR, AA, $CaCl_2$ seemed to be more effective to prevent changes in hue, retaining higher hue (86.24) after 7 days of storage.

Thus, it was observed that coatings effectively controlled enzymatic browning of apple wedges and anti-browning solutions increased the inhibitory efficiency towards browning. Our results are confirmed with Zuo *et al.* (13) who reported that the Fuji apple slices treated with combinations of ascorbic acid and citric acid showed less variation in chroma and hue during 7 days of storage.

The effects of the treatments on the TSS and TA during cold storage are shown in Table 2. In general, the total soluble solid contents initially increased then declined after achieving a peak. In untreated samples, the maximum value was obtained on second day of storage but in case of treated samples there was a delayed peak (15.7°B). The increasing trend of soluble solid content during storage, indicates the ripening process. Titratable acidity declined as storage period progressed regardless of the treatment used but remained higher in apple wedges treated with anti-browning agents and edible coatings especially of those treated with carboxymethyl cellulose. At the end of experiment, all the treated apple wedges TSS and TA content was higher than that of the control apple wedges and this finding indicated that all the coatings possessed the ability to maintain TSS and TA content of apple wedges. Both CMC and aloe vera coating in combination with anti-browning agents enhanced the inhibition of TSS and TA loss when compared with control. The most effective treatment was T_9 followed by T_5 and T_{10} for all edible coatings and anti-browning combinations. Organic acids get

Table 1. Effect of edible coatings and anti-browning agents on chroma and hue of fresh-cut apple wedges under low temperature storage.

Treatment	Chroma									Hue								
	Storage period (days)									Storage period (days)								
	0	1	2	3	4	5	6	7	Mean	0	1	2	3	4	5	6	7	Mean
T_0	26.68^{bc}	24.52^{e}	23.73^{f-g}	27.72^{ba}	25.88^{dc}	24.75^{de}	27.79^{ba}	28.93^{a}	26.25^{a}	84.77^{b-c}	82.75^{b-c}	83.14^{b-c}	83.48^{b-c}	82.20^{bc}	82.96^{b-c}	82.72^{b-c}	82.13^{c}	83.02^{d}
T_1	17.25^{b-x}	18.59^{t-x}	16.31^{m-h}	17.61^{b-x}	18.07^{t-x}	18.51^{t-x}	18.59^{t-x}	19.60^{n-q}	18.07^{ed}	86.42^{b-c}	86.99^{b-c}	84.94^{b-c}	85.78^{b-c}	85.44^{b-c}	85.24^{b-c}	86.43^{b-c}	84.75^{b-c}	85.75^{b-c}
T_2	17.07^{b-f}	16.37^{m-h}	15.08^{m-r}	15.52^{m-h}	18.44^{t-x}	18.57^{t-x}	19.27^{t-q}	18.06^{t-x}	17.30^{f}	86.79^{b-c}	87.73^{ba}	87.61^{b-c}	85.83^{b-c}	85.47^{b-c}	86.00^{b-c}	85.49^{b-c}	84.96^{b-c}	86.24^{ba}
T_3	17.39^{b-x}	16.01^{m-h}	17.15^{b-f}	19.05^{t-q}	17.85^{b-x}	19.92^{n-q}	18.84^{t-q}	19.64^{n-q}	18.23^{d}	86.12^{b-c}	87.25^{b-c}	86.30^{b-c}	85.10^{b-c}	84.35^{b-c}	86.13^{b-c}	84.59^{b-c}	83.58^{b-c}	85.43^{b-c}
T_4	18.39^{t-x}	21.63^{i-j}	21.89^{i-j}	20.37^{n-o}	24.08^{fe}	20.84^{n-j}	21.12^{m-j}	22.62^{i-g}	21.37^{b}	85.40^{b-c}	85.30^{b-c}	85.56^{b-c}	84.86^{b-c}	84.06^{b-c}	83.68^{b-c}	84.12^{b-c}	82.96^{b-c}	84.49^{dc}
T_5	13.66^{tu}	15.25^{m-r}	13.73^{t-u}	16.29^{m-h}	15.26^{m-r}	16.15^{m-h}	17.04^{b-f}	16.57^{b-h}	15.49^{h}	86.01^{b-c}	87.11^{b-c}	86.91^{b-c}	86.10^{b-c}	86.47^{b-c}	86.46^{b-c}	86.34^{b-c}	85.72^{b-c}	86.39^{a}
T_6	14.59^{t-r}	15.23^{m-r}	14.21^{t-r}	15.72^{m-h}	16.57^{b-h}	16.79^{b-h}	17.06^{b-f}	18.03^{t-x}	16.02^{g}	86.19^{b-c}	87.33^{b-c}	86.61^{b-c}	86.47^{b-c}	85.86^{b-c}	86.25^{b-c}	85.87^{b-c}	85.94^{b-c}	86.32^{ba}
T_7	16.45^{l-h}	18.57^{t-x}	16.47^{l-h}	18.48^{t-x}	19.07^{t-q}	16.62^{b-h}	19.31^{t-q}	21.30^{i-j}	18.28^{d}	87.22^{b-c}	86.77^{b-c}	87.02^{b-c}	86.51^{b-c}	85.35^{b-c}	84.35^{b-c}	84.84^{b-c}	85.22^{b-c}	85.91^{b-c}
T_8	18.99^{t-q}	17.63^{b-x}	20.74^{n-j}	19.58^{n-q}	22.56^{i-g}	20.24^{n-o}	22.01^{i-j}	23.00^{f-g}	20.59^{c}	86.39^{b-c}	85.78^{b-c}	84.65^{b-c}	85.39^{b-c}	85.87^{b-c}	84.46^{b-c}	83.05^{b-c}	83.53^{b-c}	84.89^{bc}
T_9	12.58^{u}	16.01^{m-h}	15.25^{m-r}	14.07^{t-r}	15.61^{m-h}	16.57^{b-h}	16.65^{b-h}	15.31^{m-r}	15.25^{h}	86.63^{b-c}	88.25^{a}	87.38^{b-c}	86.62^{b-c}	86.15^{b-c}	86.06^{b-c}	85.50^{b-c}	85.51^{b-c}	86.51^{a}
T_{10}	14.00^{t-r}	14.66^{t-r}	16.46^{l-h}	15.28^{m-r}	14.31^{t-r}	15.26^{m-r}	17.85^{b-x}	16.83^{b-h}	15.58^{h}	86.89^{b-c}	86.76^{b-c}	86.77^{b-c}	85.73^{b-c}	85.39^{b-c}	85.49^{b-c}	86.93^{b-c}	85.75^{b-c}	86.21^{ba}
T_{11}	15.95^{m-h}	15.16^{m-r}	17.73^{b-x}	18.59^{t-x}	16.32^{m-h}	19.23^{t-q}	19.25^{t-q}	20.08^{n-q}	17.79^{e}	87.21^{b-c}	86.56^{b-c}	86.87^{b-c}	85.26^{b-c}	85.09^{b-c}	85.12^{b-c}	86.14^{b-c}	85.41^{b-c}	85.96^{b-c}
Mean	16.92^{f}	17.47^{e}	17.40^{e}	18.19^{d}	18.67^{c}	18.62^{c}	19.56^{b}	20.00^{a}		86.34^{a}	86.55^{a}	86.15^{ba}	85.59^{b-c}	85.14^{bc}	85.18^{bc}	85.17^{bc}	84.62^{c}	85.59

Means with same superscript are not significantly different

Table 2. Effect of edible coatings and anti-browning agents on total soluble solids and titratable acidity of fresh-cut apple wedges under low temperature storage.

Treatment	Total soluble solids (°B)									Titratable acidity (%)								
	Storage period (days)									Storage period (days)								
	0	1	2	3	4	5	6	7	Mean	0	1	2	3	4	5	6	7	Mean
T_0	13.60^{n-o}	14.50^{e-f}	15.70^{a}	13.20^{q-p}	11.50^{ut}	10.60^{u}	9.30^{v}	8.10^{w}	12.06^{d}	0.536^{b-c}	0.496^{h-g}	0.469^{k-i}	0.429^{ml}	0.348^{q-p}	0.268^{v}	0.214^{xw}	0.121^{z}	0.360^{i}
T_1	13.30^{q-o}	13.60^{n-o}	13.90^{n-o}	14.60^{e-f}	15.50^{b-c}	14.20^{n-o}	13.40^{n-o}	12.10st	13.83^{b}	0.536^{b-c}	0.509^{e-g}	0.496^{h-g}	0.482^{h-i}	0.375^{n-p}	0.322^{t-s}	0.295^{t-v}	0.174^{y}	0.399^{g}
T_2	13.30^{q-o}	13.50^{n-o}	13.80^{n-o}	14.50^{e-f}	15.30^{e-c}	14.40^{e-f}	13.50^{n-o}	12.50^{sr}	13.85^{b}	0.563^{a}	0.536^{b-c}	0.523^{e-c}	0.521^{e-g}	0.383^{no}	0.335^{q-s}	0.322^{t-s}	0.188^{xy}	0.421^{f}
T_3	13.40^{n-o}	13.70^{n-o}	14.00^{n-o}	14.80^{e-f}	15.70^{a}	14.10^{n-o}	13.10^{qr}	11.80st	13.83^{b}	0.563^{a}	0.523^{e-c}	0.469^{k-i}	0.440^{kl}	0.360^{q-p}	0.308^{t-s}	0.281^{uv}	0.161^{y}	0.388^{h}
T_4	13.20^{q-p}	13.60^{n-o}	14.10^{n-o}	14.70^{e-f}	15.60^{ba}	14.20^{n-o}	13.20^{q-p}	11.90st	13.81^{b}	0.563^{a}	0.524^{e-c}	0.509^{e-g}	0.507^{e-g}	0.387^{no}	0.348^{q-p}	0.322^{t-s}	0.214^{xw}	0.422^{f}
T_5	13.10^{qr}	13.20^{q-p}	13.30^{q-o}	13.30^{q-o}	13.70^{nm}	14.00^{n-o}	14.40^{e-f}	14.50^{e-f}	13.69^{cb}	0.549^{ba}	0.548^{ba}	0.533^{e-c}	0.521^{e-g}	0.482^{h-i}	0.348^{q-p}	0.335^{q-s}	0.322^{t-s}	0.455^{b}
T_6	13.10^{qr}	13.20^{q-p}	13.50^{n-o}	13.40^{n-o}	14.00^{n-o}	14.30^{n-f}	14.70^{e-f}	15.10^{e-f}	13.91^{b}	0.549^{ba}	0.543^{b-c}	0.509^{e-g}	0.507^{e-g}	0.469^{k-i}	0.347^{q-p}	0.322^{t-s}	0.295^{t-v}	0.443^{cd}
T_7	13.10^{qr}	13.40^{n-o}	13.80^{n-o}	14.10^{n-o}	14.60^{e-f}	14.90^{e-f}	15.20^{e-f}	15.60^{ba}	14.34^{a}	0.549^{ba}	0.548^{ba}	0.511^{e-g}	0.503^{e-g}	0.456^{k-l}	0.334^{q-s}	0.308^{t-s}	0.268^{v}	0.434^{ed}
T_8	13.20^{q-p}	13.60^{n-o}	14.00^{n-o}	14.60^{e-f}	15.40^{b-c}	14.30^{n-f}	13.30^{q-o}	12.00st	13.80^{b}	0.536^{b-c}	0.531^{e-c}	0.509^{e-g}	0.501^{e-g}	0.456^{k-l}	0.360^{q-p}	0.335^{q-s}	0.228^{w}	0.432^{e}
T_9	13.10^{qr}	13.10^{qr}	13.10^{qr}	13.20^{q-p}	13.40^{n-o}	13.60^{n-o}	13.80^{n-o}	14.10^{n-o}	13.43^{c}	0.549^{ba}	0.545^{ba}	0.533^{e-c}	0.512^{e-g}	0.494^{h-g}	0.402^{nm}	0.375^{n-p}	0.348^{q-p}	0.470^{a}
T_{10}	13.10^{qr}	13.20^{q-p}	13.40^{n-o}	13.40^{n-o}	13.90^{n-o}	14.10^{n-o}	14.60^{e-f}	14.80^{e-f}	13.81^{b}	0.549^{ba}	0.543^{b-c}	0.521^{e-g}	0.496^{h-g}	0.469^{k-i}	0.389^{no}	0.362^{q-p}	0.308^{t-s}	0.455^{b}
T_{11}	13.10^{qr}	13.30^{q-o}	13.70^{n-o}	13.90^{n-o}	14.40^{e-f}	14.80^{e-f}	15.10^{e-f}	15.40^{b-c}	14.21^{a}	0.536^{b-c}	0.529^{e-c}	0.519^{e-g}	0.508^{e-g}	0.489^{h-g}	0.375^{n-p}	0.348^{q-p}	0.281^{uv}	0.448^{cb}
Mean	13.22^{d}	13.49^{c}	13.86^{b}	13.98^{b}	14.42^{a}	13.96^{b}	13.63^{c}	13.22^{d}		0.548^{a}	0.531^{b}	0.508^{c}	0.494^{d}	0.431^{e}	0.345^{f}	0.318^{g}	0.242^{h}	

Means with same superscript are not significantly different

utilized during ripening process thereby increasing the total soluble solids initially and thereafter showing a decreasing trend (Olivas *et al.,* 8). Saba and Sogvar (11) reported that the apple slices coated with CMC coating in combination with $CaCl_2$ and ascorbic acid maintains better soluble solids and titratable acidity during low temperature storage.

The purpose of this work was to investigate the effect of CMC and *Aloe vera* coatings and browning inhibitors alone and their combinations on quality maintaining of fresh-cut apple wedges. All the edible coatings possessed the ability to preserve colour of apple wedges and minimize the changes of O_2 and CO_2 inside the packs by curbing respiration rate. Coatings incorporated with browning inhibitors were able to maintain better quality when compared with anti-browning or coating alone. Browning inhibitors and edible coatings had a synergistic effect in delaying the browning process and reducing the loss of total soluble solid contents and titratable acidity till one week under low temperature storage. Thus, this could be a promising approach to preserve fresh-cut apple wedges.

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