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Studies on extending the shelf life of golden delicious apples through the application of 1-methylcyclopropene (1-MCP) and $KMnO_4$ and using various packaging materials

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Abstract
Ethylene a vital plant hormone that is essential to numerous physiological processes in plants. Ethylene initiates and modulates many ripening related processes. Following harvest, fruits and vegetables often continue to produce ethylene at varying levels based on factors such as their physiological type (climacteric vs. non-climacteric), developmental stage, and species. Consequently, ethylene gas accumulates in post-harvest micro and macro-environments, including within different types of packaging like wooden boxes, corrugated fiber boxes (CFB), and shrink-wrap packaging. Hence, ethylene management is essential to enhance the shelf life of fresh fruit through a conjunctive approach like by manipulating physiology by suppressing ethylene production and action, and by physical or chemical scavenging of ethylene from the postharvest environments. Among different strategies to manage ethylene, application of 1-Methylcyclopropene (1-MCP) followed by $KMnO_4$ has emerged as a useful commercial tool. This investigation was undertaken to study the effect of different packaging materials using 1-MCP and $KMnO_4$. For this evaluation, freshly harvested Golden Delicious apples were packed in different packaging materials (Wooden boxes, Corrugated Fiber boxes and Shrink-wrapped boxes) and were subjected to various treatments which included T_1 (Control), T_2 (1-MCP), T_3 ($KMnO_4$) and were stored under ambient conditions (18±5 °C, 60%) for 160 days to assess the quality attributes (Starch iodine rating (1-6 point scale), Total sugars (%), Ascorbic acid (mg/100 g), Pectin (%), carotenoid (mg/100 g). and skin colour) during storage at 20 days of interval. However, the outcome of the study suggested that the combination of 1-MCP treatment along with shrink-wrap packaging retained the maximum quality attributes, followed by $KMnO_4$ treatment with shrink-wrap packaging which underscores the importance of packaging material selection and ethylene management strategies in preserving the quality and extending the shelf life of fresh produce.

Keywords: Apple c.v golden delicious, 1- MCP, $KMnO_4$, shelf-life

Introduction
The apple (*Malus* × *domestica* Borkh.) stands as one of the most widely cultivated fruit trees across the globe, boasting a staggering production of 83.1 million tons (USDA, 2023). Jammu and Kashmir, consistently positioned first place in India, contributes significantly to this global output, with an annual production ranging from approximately 21-22 lakh tons (National Horticulture Board). Climacteric fruits possess the ability to naturally produce ethylene, a hormone that accelerates the ripening process and triggers various biochemical and enzymatic reactions (Farcuh *et al.*, 2018) [4]. The emission of ethylene additionally stimulates the respiration rate and diminishes the shelf life of climacteric fruits (Xin *et al.*, 2017) [5]. Diverse assortments and varying storage conditions for fruits have become increasingly significant for fruit growers. This is particularly crucial in preserving fruit quality for making it available during off season sale in the market several months post-harvest, when prices tend to be higher. Harvest maturity for fresh fruit consumption is determined in diverse ways, influenced by factors such as species, cultivar, storage conditions, consumer proximity, and more (Milinković *et al.*, 2018) [1]. Presently, the controlled atmosphere (CA) technique stands as the most prevalent method for storing apples.

However, despite the controlled atmosphere (CA) storage of apples, quality losses and physiological disorders may still occur. Therefore, additional postharvest techniques are necessary to uphold the quality of apples during storage (Thewes *et al*., 2015) [2]. The application of the ethylene perception inhibitor, 1-methylcyclopropene (1-MCP), marketed under the name Smart Fresh™, is widely adopted as an additional method to preserve the quality of apples, offering the ability to release the gaseous form in order to inhibit ethylene receptors in fruits, thereby delaying the onset of physiological processes (Nock *et al*., 2013) [9]. 1-MCP, once released, competes with ethylene for binding to receptor sites, effectively preventing the formation of ethylene receptor complexes. This mechanism effectively halts the ethylene-induced fruit ripening process. The commercial development prospects for this compound are promising, particularly for climacteric fruits like apples, where controlling ethylene production is linked to improved storage capabilities B. Watkins *et al*., 2000) [3]. Additionally, other techniques such as Potassium permanganate ($KMnO_4$) have shown efficacy in lowering ethylene levels through its oxidation into carbon dioxide and water (Heidari *et al*., 2011) [6]. Utilizing potassium permanganate-impregnated sachets for ethylene absorption presents an alternative method to mitigate ethylene production during fruit maturation, effectively extending both the pre-climacteric phase and the post-harvest lifespan of the fruits (Sanches *et al*., 2019) [7] due to their capability to absorb and oxidize ethylene, these sachets convert it into water, carbon dioxide, manganese dioxide, and potassium (Nisarga *et al*., 2022) [8].

Maintaining food quality and safety while reducing post-harvest losses is vital for sustaining a robust food system. Effective packaging aids in preserving food quality throughout its storage duration. The four primary and interconnected functions of packaging include containment, protection, convenience, and communication. According to Robertson (2014) [10], functions such as traceability, convenience, and tamper indication are considered less critical compared to the primary functions. Various packaging methods are utilized for packaging apples, encompassing a range of techniques such as wooden boxes, corrugated fiber boxes and shrink wrap packaging (Bhat *et al*., 2023) [11]. The hygiene qualifications of wood have been questioned due to its absorbent and porous nature. In contrast, corrugated fiber boxes are frequently preferred for crafting custom packaging for products. Their durability and resistance to crushing render them an excellent choice for safeguarding apples during transportation to market while the concept of shrink wrap offers a soft and silent texture, unlike other packaging materials that are often rigid and brittle. This attribute lends shrink wrap a high degree of versatility, allowing the film to conform effortlessly to any shape as wrapping fruits with polymeric film forms a protective barrier between the fruit surface and the surrounding environment, effectively retaining moisture within the fruit (Thakur *et al*., 2017) [12].

Procurement of raw material

The investigation utilized high-quality analytical-grade chemicals obtained from registered dealers by the division. Healthy and mature Golden Delicious apple fruits were carefully selected at physiological maturity for the study. After harvest, the apples underwent pre-cooling in shaded conditions before being packed in various packaging materials such as wooden boxes, corrugated fiberboard (CFB) boxes, and shrink-wrap boxes. Additionally, the fruits were subjected to different treatments: T_1 (Control), T_2 (1-MCP), and T_3 ($KMnO_4$). Some fruits were treated with 1 ppm 1-MCP (SmartFresh) cards or placed in boxes, while others were treated with 5g $KMnO_4$ sachets or left untreated (Control). All samples were stored under ambient conditions (18±3 ℃) at 60% relative humidity for a storage period of 160 days.

Materials and Methods

Evaluation of physico-chemical properties of apples

Starch iodine rating (1-6 point scale)

Starch content in apples was assessed immediately post-harvest and at 20-day intervals over a storage period of 160 days using the starch-iodine test. An iodine solution was prepared by dissolving 4 g of KI in 400 ml of distilled water, supplemented with 1 g of iodine. Apples were halved along the equator and immersed in the iodine solution for 1 minute, followed by a 2-minute rest period after removal. Each slice was then swiftly rinsed with clean water, and starch content was estimated using a Generic chart scoring system ranging from 1 (highest starch content) to 6 (lowest starch content). The extent of colour was rated as under:

1. Starch present throughout (Entire surface coloured).
2. Starch absent from core area.
3. Starch absent from core area and vascular bundles.
4. Starch present in outer half of cortex.
5. Starch present only in narrow bands under skin.
6. No starch present (No blue black colour).

Estimation of sugars

The Lane and Eynon technique was used to calculate the total and reducing sugars (Ranganna, 1997) [25]. In this process, phenolphthalein indicator was added to a determined volume of apple juice (10 mL) and the mixture was neutralized with NaOH. After that, 2 milliliters of lead acetate were added, and the mixture was left aside for ten minutes. Next, two milliliters of potassium oxalate were added, and distilled water was used to get the amount down to 250 ml. After filtering the mixture, it was titrated using methylene blue as an indicator against Fehling's A and Fehling's B solutions (5 mL each, diluted with 25 mL of distilled water). Total and reducing sugar content was estimated using following Equation:

$$\text{Total and Reducing sugars (\%)} = \frac{\text{Fehling's factor (Ff) x total volume (Vd)}}{\text{titre value (Tv) x weightof sample (Ws)}} \text{ x 100 eq.}$$

Where

Ff = Fehling's factor; Tv = titre value; Vd = total volume made up; Ws = weight of sample

Non-reducing sugar = total sugar – reducing sugar (Wani *et al*., 2024) [13].

Vitamin-C (g/100mg)

The vitamin C content was estimated as per assay method given by Ranganna (1997) [25]. Preparation of 3% Meta phosphoric acid (HPO_3) solution entails dissolving 15g of 3% Meta phosphoric acid in 500ml of distilled water. Subsequently, 100 mg of ascorbic acid are dissolved in 100 milliliters of 3% Meta phosphoric acid to create standard asc orbic acid, which is then diluted to 10 milliliters with 3% H PO_3 (1 milliliter equals 0.1 milligrams of ascorbic acid).52 mg of sodium salt of 2,6dichlorophenol indophenol is dissol ved in 150 ml of hot distilled water with 42 mg of sodium bi carbonate ($NaHCO_3$) to generate the dye solution. This is th en diluted with 200 ml of distilled water and refrigerated.To standardize the dye, 5 milliliters of standard ascorbic acid so lution are mixed with 5 milliliters of HPO_3, and the mixture is titrated against the dye solution until a 15second period of persistent pink hue is seen.Afterwards, the dye factor is calculated. Sample preparation entails filtering after 10 g of the sample has been mixed with 100ml of 3% HPO3.La stly, 10 milliliters of the sample are titrated against the refer ence dye for the ascorbic acid assay until a pink hue lasts for 15 seconds. Ascorbic acid content of the sample was calculated by using the following formula:

$$\text{Vitamin C} \left(\frac{\text{mg}}{100\text{ml}}\right) \frac{\text{Titre} \times \text{Dye Equivalent} \times \text{Dilution}}{\textit{weight of sample}} \text{ x 100 eq.}$$

Pectin content (%)

Pectin was extracted as calcium pectate from fresh fruit samples. A 5g sample was boiled with 400ml of 0.05N HCl for 6 minutes, cooled, and made up to 100ml with distilled water. After filtration, 100ml of filtrate was neutralized with 1N NaOH, left undisturbed for 24 hours, and then treated with 50ml of 1N acetic acid and 25ml of 1N $CaCl_2$. After precipitation, the solution was boiled, filtered, and the precipitate washed with boiling water until chloride-free. The filter paper containing the precipitate was dried for 24 hours at 60 °C, cooled, and weighed (Wani *et al*., 2024) [13] The pectin as per cent calcium pectate was determined using the following equation:

$$\text{Calcium pectate \%} = \frac{\text{wt.of calcium pectate x 500}}{\text{ml of filtrate taken for estimation x wt.of sample}} \times 100$$

Carotenoid content (mg/100 g)

Total carotenoids as beta carotene equivalents were determined using the method with slight modifications (Kimura & Rodriguez-Amaya, 2004.) [22]. Two grams of homogenized sample were extracted with cold acetone until the residue became colorless, followed by filtration. The filtered acetone extract (25ml) was mixed with 20ml of petroleum ether and allowed to separate into two phases. The aqueous phase was discarded, and the organic phase was collected. After passing through anhydrous sodium sulfate to remove residual water, the petroleum ether phase was collected in a 100ml volumetric flask, made up to 100ml with petroleum ether, and its absorbance was measured at 450nm using petroleum ether as a blank. The total carotenoids as mg beta carotene equivalents /100 g were calculated as under:-

Total carotenoids (mg/100 g) = (delta A/el) x MW x D x (V/G)

Where delta A: is absorbance,
e: the beta carotene molar extinction coefficient (2590)
l: the cell path length (1cm),
MW: molar weight of beta-carotene (536.8), D a dilution factor,
V: final volume (ml) and
G: sample weight (g).

Hunter Lab colorimeter analysis

The fruit surface color was assessed using a Hunter Lab colorimeter (Model CR-2000, Minolta, Osaka, Japan) equipped with an 8-mm measuring head and C illumination (6774 K). Calibration was performed using the manufacturer's standard white plate. Color changes were quantified in the L*, a*, b* color space, where L* represents the lightness of the fruit's color, ranging from black (L* = 0) to white (L* = 100). A negative value of a* indicates a green color, while a positive value indicates a red-purple color. Similarly, a positive value of b* indicates a yellow color, while a negative value indicates a blue color. The calculation of ΔE, indicating the color difference relative to brightness, was conducted. using the following Equation provided below.

$$\Delta E = \sqrt{(L_0{}^* - L^*)^2 + (a_0{}^* - a^*)^2 + (b_0{}^* - b^*)^2}$$

Where L_0^*, a_0^*, and b_0^* represents the color data based on the samples, while the color of the measured instantaneous data was indicated by L*, a*, and b*.

Results and Discussions

Quality determination for shelf life assessment of Golden delicious apples using different packaging materials and ethylene inhibitors /absorber under 160 days of ambient storage

Effect on Starch iodine rating (1-6 point scale)

Starch iodine rating (on a 1-6 point scale) for Golden Delicious apples during 160 days of ambient storage is represented in Table 1. The rise in starch iodine rating during storage conditions reveals that starch undergoes conversion into sugars as ripening advances, serving to fulfill the metabolic respiratory requirements in apples (Wani *et al*., 2024) [13]. Data depicted in Table 1 showed that P_3T_2 (Shrinkwrap + 1-MCP) exhibited a starch index of 5.5, compared to an initial value of 3.5 while P_1T_1 (Wooden + Control) showed a starch index of 6.00 from an initial value of 3.5 up to 20 days of ambient storage. This indicates that P_3T_2 (Shrinkwrap + 1-MCP) demonstrated greater efficacy in preventing starch degradation by inhibiting the ethylene receptors to biosynthesise ethylene (Brizzolara *et al*., 2020) [14] According to (Shafi *et al*., 2015) [16] the rapid conversion of starch into simple sugars observed in P_1T_1 (Wooden + Control) and the slower process in treated fruits (Shrinkwrap + 1-MCP) can be attributed to the inhibitory effect of Shrinkwrap + 1-MCP on the ripening process.

Effect on Total, Reducing and Non- reducing sugars

Table 2, 3 and 4 depicted data on the effect of various packaging materials and ethylene inhibitors/absorbers on the Total sugars (%), reducing sugars and non- reducing sugars. Initially, there was an upward trend in total and reducing sugars up to 40 days of storage, followed by a subsequent decline. In the study, the decrease in total and reducing sugars was notable in P_1T_1 (Wooden + Control), declining from an initial value of 9.77 to 7.56 and 8.62 to 6.69 while the minimum decline was observed in P_3T_2 (Shrinkwrap + 1-MCP), decreasing from 9.77 to 8.67 and 8.62 to 6.69 respectively over 160 days of ambient storage. The rise in total and reducing sugar levels during storage may be attributed to the hydrolysis of starch into sugars (Zou *et al*., 2022) [15]. Conversely, according to Singh (1998) the decrease in total sugars over time could be due to the accelerated utilization of carbohydrates in respiration, senescence, and oxidation processes. In contrast, non – reducing sugars also show declining percentage of 1.15 to

0.89 in P_1T_1 (Wooden+ Control) while minimum decline was observed in P_3T_2 (Shrinkwrap+1-MCP) from an initial value of 1.15 to 1.02 Ali *et al*. (2004) [17].

Effect on Vitamin C

The results of Vitamin C (mg/100 g) content of Golden delicious apples is presented in table 5. Degradation in Vitamin C content during storage is known to be because of its antioxidant activity or can be due to the irreversible oxidation of Vitamin C. On comparing the treatments the maximum Vitamin C content was found to be 7.14 in P_3T_2 (Shrinkwrap+1-MCP) from an initial value of 7.90, whereas minimum values of Vitamin C content was found to be 6.10 in P_1T_1 (Wooden+ Control) from an initial value of 7.90. Hence, P_3T_2 (Shrinkwrap + 1-MCP) effectively preserves Vitamin C content by reducing active oxygen levels and inhibiting reactive oxygen species buildup through enhanced ROS metabolic enzyme activity, as indicated by Lin *et al.* (2022) [18]. Additionally, shrink wrapping creates a barrier that limits oxygen concentration around the fruit, leading to higher Vitamin C content, as suggested by Thakur *et al.* (2018) [12].

Table 1: Effect of different packaging materials and ethylene inhibitors/absorbers on Starch iodine rating (1-6 point scale) of Golden Delicious apples under 160 days of ambient storage

	S1 (0-DAS)			Mean SP	S2 (20-DAS)			Mean SP	S3 (40-DAS)			Mean SP	S4 (60-DAS)			Mean SP	S5 (80-DAS)			Mean SP
	T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3	
P_1	3.5	3.5	3.5	3.50	6.00	5.90	6.00	5.96	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
P_2	3.5	3.5	3.5	3.50	6.00	5.70	6.00	5.90	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
P_3	3.5	3.5	3.5	3.50	6.00	5.50	6.00	5.83	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Mean ST	3.50	3.50	3.50	3.50	6.00	5.70	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
	S6 (100-DAS)			Mean SP	S7 (120-DAS)			Mean SP	S8 (140-DAS)			Mean SP	S9 (160-DAS)			Mean SP	Mean T	Mean P		
	T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3					
P_1	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	5.72	5.71		
P_2	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	5.60	5.71		
P_3	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	5.72	5.70		
Mean ST	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00				

Table 2: Effect of different packaging materials and ethylene inhibitors/absorbers on Total sugars (%) of Golden Delicious apples under 160 days of ambient storage

	S1 (0-DAS)			Mean SP	S2 (20-DAS)			Mean SP	S3 (40-DAS)			Mean SP	S4 (60-DAS)			Mean SP	S5 (80-DAS)			Mean SP
	T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3	
P_1	9.77	9.77	9.77	9.77	10.71	10.28	10.54	10.51	10.11	10.79	10.45	10.45	9.60	10.20	10.03	9.94	9.01	9.94	9.52	9.49
P_2	9.77	9.77	9.77	9.77	10.79	10.28	10.45	10.50	10.28	10.71	10.62	10.53	9.60	10.45	9.86	9.97	9.18	10.11	9.69	9.66
P_3	9.77	9.77	9.77	9.77	10.45	10.20	10.37	10.34	10.79	10.54	10.28	10.55	10.11	10.71	10.03	10.28	9.60	10.20	9.77	9.86
Mean S T	9.77	9.77	9.77	9.77	10.65	10.25	10.45	10.45	10.39	10.68	10.47	10.50	9.77	10.45	9.97	10.06	9.26	10.08	9.66	9.66
	S6 (100-DAS)			Mean SP	S7 (120-DAS)			Mean SP	S8 (140-DAS)			Mean SP	S9 (160-DAS)			Mean SP	Mean T	Mean P		
	T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3					
P_1	8.50	9.43	9.01	8.98	8.16	8.75	8.41	8.44	7.73	8.41	8.07	8.07	7.56	7.99	7.65	7.73	9.24	9.29		
P_2	8.84	9.69	9.26	9.26	8.50	9.35	8.67	8.84	8.16	9.09	8.33	8.52	7.73	8.41	7.90	8.01	9.70	9.47		
P_3	9.18	9.94	9.35	9.49	8.58	9.43	9.01	9.00	8.24	9.18	8.50	8.64	7.82	8.67	8.07	8.18	9.39	9.57		
Mean ST	8.84	9.68	9.20	9.24	8.41	9.17	8.69	8.76	8.04	8.89	8.3	8.41	7.70	8.36	7.87	7.98				

Table 3: Effect of different packaging materials and ethylene inhibitors/absorbers on Reducing sugars (%) of Golden Delicious apples under 160 days of ambient storage

	S1 (0-DAS)			Mean SP	S2 (20-DAS)			Mean SP	S3 (40-DAS)			Mean SP	S4 (60-DAS)			Mean SP	S5 (80-DAS)			Mean SP
	T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3	
P_1	8.62	8.62	8.62	8.62	9.45	9.07	9.30	9.28	8.95	9.52	9.22	9.23	8.47	9.00	8.85	8.77	7.95	8.77	8.40	8.37
P_2	8.62	8.62	8.62	8.62	9.52	9.07	9.22	9.27	9.07	9.45	9.37	9.29	8.47	9.22	8.70	8.79	8.10	8.92	8.55	8.52
P_3	8.62	8.62	8.62	8.62	9.22	9.00	9.15	9.12	9.52	9.30	9.07	9.29	8.92	9.45	8.85	9.07	8.47	9.00	8.62	8.69
Mean ST	8.62	8.62	8.62	8.62	9.40	9.05	9.23	9.23	9.18	9.42	9.22	9.27	8.62	9.22	8.80	8.88	8.17	8.90	8.52	8.53
	S6 (100-DAS)			Mean SP	S7 (120-DAS)			Mean SP	S8 (140-DAS)			Mean SP	S9 (160-DAS)			Mean SP	Mean T	Mean P		
	T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3					
P_1	7.50	8.32	7.95	7.92	7.20	7.72	7.42	7.45	6.85	7.42	7.12	7.13	6.69	7.05	6.75	6.83	8.12	8.21		
P_2	7.80	8.55	8.13	8.16	7.50	8.25	7.65	7.80	7.20	8.02	7.35	7.52	6.82	7.42	6.97	7.07	8.58	8.35		
P_3	8.10	8.77	8.25	8.37	7.53	8.32	7.95	7.93	7.27	8.10	7.50	7.62	6.90	7.65	7.12	7.22	8.29	8.43		
Mean ST	7.80	8.55	8.11	8.15	7.41	8.10	7.67	7.73	7.10	7.84	7.32	7.43	6.80	7.37	6.95	7.04				

Table 4: Effect of different packaging materials and ethylene inhibitors/absorbers on Non-Reducing sugars (%) of Golden Delicious apples under 160 days of ambient storage

	S1 (0-DAS)			Mean SP	S2 (20-DAS)			Mean SP	S3 (40-DAS)			Mean SP	S4 (60-DAS)			Mean SP	S5 (80-DAS)			Mean SP
	T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3	
P_1	1.15	1.15	1.15	1.15	1.26	1.21	1.24	*1.24*	1.19	1.27	1.23	1.23	1.13	1.20	1.18	1.17	1.06	1.17	1.12	1.11
P_2	1.15	1.15	1.15	1.15	1.27	1.21	1.23	1.24	1.21	1.26	1.25	1.24	1.13	1.23	1.16	1.17	1.08	1.19	1.14	1.13
P_3	1.15	1.15	1.15	1.15	1.23	1.20	1.22	1.22	1.27	1.24	1.27	1.26	1.19	1.26	1.18	1.21	1.13	1.20	1.15	1.16
Mean ST	1.15	1.15	1.15	1.15	1.25	1.21	1.23	1.23	1.22	1.26	1.25	1.24	1.15	1.23	1.17	1.18	1.09	1.19	1.14	1.14
	S6 (100-DAS)			Mean SP	S7 (120-DAS)			Mean SP	S8 (140-DAS)			Mean SP	S9 (160-DAS)			Mean SP	Mean T	Mean P		
	T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3					
P_1	1.00	1.11	1.06	1.06	0.96	1.03	0.99	0.99	0.91	0.99	0.95	0.95	0.89	0.94	0.90	0.91	1.07	1.08		
P_2	1.04	1.14	1.09	1.09	1.00	1.10	1.02	1.04	0.96	1.07	0.98	1.00	0.91	0.99	0.93	0.94	1.12	1.11		
P_3	1.08	1.17	1.10	1.12	1.01	1.11	1.06	1.06	0.97	1.08	1.00	1.01	0.92	1.02	0.95	0.96	1.09	1.10		
Mean ST	1.04	1.14	1.08	1.08	0.99	1.08	1.02	1.03	0.95	1.05	0.98	0.99	0.91	0.98	0.93	0.94				

Table 5: Effect of different packaging materials and ethylene inhibitors /absorbers on Vitamin C (mg/100 g) of Golden Delicious apples under 160 days of ambient storage

	S1 (0-DAS)			Mean SP	S2 (20-DAS)			Mean SP	S3 (40-DAS)			Mean SP	S4 (60-DAS)			Mean SP	S5 (80-DAS)			Mean SP
	T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3	
P_1	7.9	7.9	7.9	7.9	7.40	7.60	7.52	7.50	7.30	7.51	7.33	7.38	7.21	7.39	7.26	7.28	7.14	7.27	7.17	7.19
P_2	7.9	7.9	7.9	7.9	7.49	7.62	7.54	7.55	7.33	7.53	7.42	7.42	7.25	7.43	7.36	7.34	7.19	7.32	7.22	7.24
P_3	7.9	7.9	7.9	7.9	7.50	7.67	7.60	7.59	7.44	7.55	7.51	7.50	7.35	7.45	7.42	7.40	7.26	7.40	7.31	7.32
Mean ST	7.90	7.90	7.90	7.90	7.46	7.63	7.55	7.55	7.36	7.53	7.42	7.44	7.27	7.42	7.35	7.35	7.20	7.33	7.23	7.25
	S6 (100-DAS)			Mean SP	S7 (120-DAS)			Mean SP	S8 (140-DAS)			Mean SP	S9 (160-DAS)			Mean SP	Mean T	Mean P		
	T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3					
P_1	7.90	7.20	7.10	7.40	7.00	7.15	7.30	7.15	6.60	7.70	6.90	7.06	6.10	7.00	6.20	6.43	7.26	7.25		
P_2	7.12	7.25	7.17	7.18	7.60	7.20	7.11	7.30	7.00	7.16	7.70	7.28	6.40	7.90	7.10	7.13	7.44	7.37		
P_3	7.20	7.35	7.24	7.26	7.17	7.26	7.19	7.20	7.11	7.20	7.13	7.14	7.26	7.14	7.60	7.33	7.33	7.40		
Mean ST	7.41	7.27	7.17	7.28	7.26	7.20	7.20	7.22	6.90	7.35	7.24	7.17	6.59	7.35	6.97	7.16				

Effect on pectin

Decrease in pectin content can be due to the enzyme activity particularly by methyl pectin esterase and polygalacturonase enzymes (Wijewardane *et al.*, 2009) [19]. As shown in table 6, it is clear that pectin content showed significant decrease with the increase in storage period.). Upto 100 days of storage, maximum pectin content was found to be 0.07 (0.75%) in P_3T_2 (Shrinkwrap+1-MCP) from an initial value of 0.40 (0.94%), whereas upto 20 days of storage 0.19 (0.83%) was found to be in P_1T_1 (Wooden+ Control) from an initial value of 0.40 (0.94%). Thus, P_3T_2 (Shrinkwrap + 1-MCP) excels in preserving pectin content by inhibiting cell wall decomposition and suppressing associated enzyme activities, as noted by Watkins *et al*. (2006) [3]. Additionally, shrink wrapping enhances the efficacy of 1-MCP by creating a barrier that prevents its escape, thereby retaining fruit pectin content, as suggested by Thakur *et al*. (2017) [12].

Effect on carotenoid

According to Zuzana (2020) [20], carotenoid content showed significant decrease with the increase in storage period (table 7). The major cause of carotenoid loss during storage is however due to the enzymatic and non-enzymatic oxidation, which depends on the availability of oxygen and the carotenoid structure. It is stimulated by light, heat, some metals, enzymes and peroxides and is inhibited by antioxidants (D.B Rodriguez-Amaya *et al.,* 1999) [21]. Highest carotenoid content was found to be 1.22 in P_3T_2 (Shrinkwrap+1-MCP) from an initial value of 2.30, whereas lowest carotenoids content was found to be 1.66 in P_1T_1 (Wooden+ Control) from an initial value of 2.30, which indicates that P_3T_2 (Shrinkwrap + 1-MCP) effectively preserves carotenoid content by delaying the ethylene-induced climacteric peak and slowing down carotenoid degradation, as demonstrated by Elhadi *et al*. (2018) [24]. Moreover, shrink wrap enhances total antioxidant capacity and radical scavenging abilities, thereby aiding in the retention of fruit carotenoid content, as proposed by Rao *et al*. (2015) [23].

Effect on Instrumental Colour (*L, *a**, *b**and ΔE)**

Colour changes in chlorophyll lead to pigment breakdown, which is the source of the apple's color shift.Chlorophyll pro duction is shown during the developmental stage; however, chlorophyll breakdown is seen during maturity and ripening, which lessens the greenish color. The results shown in table 8, 9, 10 and 11 represents color coordinate values (L*, a*, b*, and ΔE) of apples following postharvest application of 1-MCP and $KMnO_4$. The decrease in L* and a* values and increase in b* and ΔE values may be attributed to ripening and the degradation of chlorophyll pigments. However, P_3T_2 (Shrink wrap + 1-MCP) excelled in preserving fruit color attributes by delaying chlorophyll loss and pigment unmasking, achieved through 1-MCP's inhibition of ethylene receptors on the endoplasmic reticulum membrane, as noted by Watkins *et al*. (2006) [3]. Additionally, shrink wrap acted as a barrier, effectively protecting fruit color and gloss, as proposed by Thakur *et al*. (2017) [12].

Table 6: Effect of different packaging materials and ethylene inhibitors/absorbers on Pectin (%) of Golden Delicious apples under 160 days of ambient storage

	S1 (0-DAS)			Mean SP	S2 (20-DAS)			Mean SP	S3 (40-DAS)			Mean SP	S4 (60-DAS)			Mean SP	S5 (80-DAS)			Mean SP
	T1	T2	T3		T1	T2	T3		T1	T2	T3		T1	T2	T3		T1	T2	T3	
P_1	0.4 (0.94)	0.4 (0.94)	0.4 (0.94)	0.4 (0.94)	0.00 (0.70)	0.25 (0.86)	0.00 (0.70)	0.08 (0.75)	0.00 (0.70)	0.15 (0.80)	0.00 (0.70)	0.05 (0.73)	0.00 (0.70)	0.07 (0.75)	0.00 (0.70)	0.02 (0.71)	0.00 (0.70)	0.00 (0.70)	0.00 (0.70)	0.00 (0.70)
P_2	0.40 (0.94)	0.40 (0.94)	0.40 (0.94)	0.40 (0.94)	0.00 (0.70)	0.28 (0.88)	0.15 (0.80)	0.14 (0.79)	0.00 (0.70)	0.21 (0.84)	0.00 (0.70)	0.07 (0.74)	0.00 (0.70)	0.13 (0.79)	0.00 (0.70)	0.04 (0.73)	0.00 (0.70)	0.05 (0.74)	0.00 (0.70)	0.01 (0.71)
P_3	0.40 (0.94)	0.40 (0.94)	0.40 (0.94)	0.40 (0.94)	0.19 (0.83)	0.25 (0.86)	0.20 (0.83)	0.21 (0.84)	0.00 (0.70)	0.21 (0.84)	0.00 (0.70)	0.07 (0.74)	0.00 (0.70)	0.15 (0.80)	0.00 (0.70)	0.05 (0.73)	0.00 (0.70)	0.10 (0.77)	0.00 (0.70)	0.03 (0.72)
Mean ST	0.40 (0.94)	0. (0.94)	0.40 (0.94)	0.40 (0.94)	0.06 (0.74)	0.26 (0.86)	0.12 (0.77)	0.15 (0.79)	0.00 (0.70)	0.19 (0.82)	0.00 (0.70)	0.06 (0.73)	0.00 (0.70)	0.12 (0.78)	0.00 (0.70)	0.04 (0.72)	0.00 (0.70)	0.05 (0.73)	0.00 (0.70)	0.02 (0.71)
	S6 (100-DAS)			Mean SP	Mean T	Mean P														
	T1	T2	T3																	
P_1	0.00 (0.70)	0.00 (0.70)	0.00 (0.70)	0.00 (0.70)	0.05 (0.74)	0.06 (0.75)														
P_2	(0.70)	0.00 (0.70)	0.00 (0.70)	0.00 (0.70)	0.11 (0.80)	0.07 (0.76)														
P_3	0.00 (0.70)	0.07 (0.75)	0.00 (0.70	0.02 (0.72)	0.05 (0.74)	0.08 (0.78)														
Mean ST	0.00 (0.70)	0.02 (0.71)	0.00 (0.70)	0.01 (0.71)																

Table 7: Effect of different packaging materials and ethylene inhibitors/absorbers on Carotenoid (mg/100 g) of Golden Delicious apples under 160 days of ambient storage

	S1 (0-DAS)			Mean SP	S2 (20-DAS)			Mean SP	S3 (40-DAS)			Mean SP	S4 (60-DAS)			Mean SP	S5 (80-DAS)			Mean SP
	T1	T2	T3		T1	T2	T3		T1	T2	T3		T1	T2	T3		T1	T2	T3	
P_1	2.3	2.3	2.3	2.30	1.93	2.01	1.97	1.97	1.86	1.92	1.89	1.89	1.73	1.85	1.76	1.78	1.60	1.71	1.67	1.66
P_2	2.3	2.3	2.3	2.30	2.03	2.06	2.04	2.04	1.88	2.00	1.97	1.95	1.75	1.92	1.86	1.84	1.63	1.83	1.73	1.73
P_3	2.3	2.3	2.3	2.30	2.05	2.10	2.11	2.08	1.89	2.08	2.00	1.99	1.73	2.00	1.98	1.90	1.65	1.95	1.88	1.83
Mean ST	2.30	2.30	2.30	2.30	2.00	2.05	2.04	2.03	1.88	2.00	1.95	1.94	1.74	1.92	1.87	1.84	1.63	1.83	1.76	1.74
	S6 (100-DAS)			Mean SP	S7 (120-DAS)			Mean SP	S8 (140-DAS)			Mean SP	S9 (160-DAS)			Mean SP	Mean T	Mean P		
	T1	T2	T3		T1	T2	T3		T1	T2	T3		T1	T2	T3					
P_1	1.54	1.63	1.59	1.59	1.40	1.58	1.43	1.47	1.32	1.46	1.39	1.39	1.22	1.38	1.26	1.28	1.69	1.71		
P_2	1.56	1.76	1.68	1.67	1.42	1.65	1.55	1.54	1.35	1.58	1.43	1.45	1.29	1.50	1.32	1.37	1.85	1.77		
P_3	1.59	1.89	1.72	1.73	1.48	1.78	1.67	1.64	1.40	1.70	1.55	1.55	1.31	1.66	1.43	1.46	1.78	1.84		
Mean ST	1.56	1.76	1.66	1.66	1.43	1.67	1.55	1.55	1.36	1.58	1.46	1.46	1.27	1.51	1.33	1.37				

Table 8: Effect of different packaging materials and ethylene inhibitors /absorbers on Instrumental Colour (L*) of Golden Delicious apples under 160 days of ambient storage

	S_1 (0-DAS)			Mean SP	S_2 (20-DAS)			Mean SP	S_3 (40-DAS)			Mean SP	S_4 (60-DAS)			Mean SP	S_5 (80-DAS)			Mean SP
	T1	T2	T3		T1	T2	T3		T1	T2	T3		T1	T2	T3		T1	T2	T3	
P_1	64.7	64.7	64.7	64.7	55.02	58.59	56.28	56.63	53.62	56.82	54.33	54.92	51.09	53.01	53.25	52.45	49.97	51.32	52.17	51.15
P_2	64.7	64.7	64.7	64.7	57.43	59.87	58.01	58.43	55.88	57.89	56.92	56.89	52.17	55.39	54.60	54.05	50.47	52.7	51.85	51.67
P_3	64.7	64.7	64.7	64.7	59.48	62.27	60.43	60.72	57.67	61.59	59.29	59.51	56.07	59.77	57.92	57.92	53.51	58.29	55.56	55.78
Mean ST	64.70	64.70	64.70	64.70	57.31	60.24	58.24	58.60	55.72	58.77	56.85	57.11	53.11	56.06	55.26	54.81	51.32	54.10	53.19	52.87
	S_6 (100-DAS)			Mean SP	S_7 (120-DAS)			Mean SP	S_8 (140-DAS)			Mean SP	S_9 (160-DAS)			Mean SP	Mean T	Mean P		
	T1	T2	T3		T1	T2	T3		T1	T2	T3		T1	T2	T3					
P_1	49.07	50.87	50.08	50.00	47.66	50.01	49.97	49.21	44.36	49.28	47.05	46.89	43.56	47.55	45.24	45.45	52.54	52.38		
P_2	49.67	51.98	50.18	50.61	48.95	50.10	49.87	49.64	46.78	49.95	47.49	48.07	44.76	48.96	45.88	46.53	55.47	53.40		
P_3	51.77	56.77	54.86	54.46	50.67	55.87	53.66	53.40	48.33	53.22	52.87	51.47	46.68	51.54	50.87	49.69	54.17	56.41		
Mean ST	50.17	53.21	51.71	51.70	49.09	51.99	51.17	50.75	46.49	50.82	49.14	48.81	45.00	49.35	47.33	47.23				

Table 9: Effect of different packaging materials and ethylene inhibitors/absorbers on Instrumental Colour (a*) of Golden Delicious apples under 160 days of ambient storage

	S1 (0-DAS)			Mean SP	S2 (20-DAS)			Mean SP	S3 (40-DAS)			Mean SP	S4 (60-DAS)			Mean SP	S5 (80-DAS)			Mean SP
	T1	T2	T3		T1	T2	T3		T1	T2	T3		T1	T2	T3		T1	T2	T3	
P_1	-10.62	-10.62	-10.62	-10.62	-5.16	-7.25	-6.2	-6.20	-4.02	-6.9	-5.3	-5.40	-3.9	-5.2	-4.1	-4.4	-3.2	-4.5	-3.75	-3.81
P_2	-10.62	-10.62	-10.62	-10.62	-6.7	-8.8	-7.65	-7.71	-5.5	-7.75	-6.2	-6.48	-4.33	-6.67	-5.14	-5.38	-3.8	-5.56	-4.35	-4.57
P_3	-10.62	-10.62	-10.62	-10.62	-7.76	-9.99	-8.56	-8.77	-6.6	-8.88	-7.5	-7.66	-5.3	-7.95	-6.5	-6.58	-4.4	-6.90	-5.00	-5.43
Mean ST	-10.62	-10.62	-10.62	-10.62	-6.54	-8.68	-7.47	-7.56	-5.37	-7.84	-6.33	-6.52	-4.51	-6.61	-5.25	-5.45	-3.80	-5.65	-4.37	-4.61
	S6 (100-DAS)			Mean SP	S7 (120-DAS)			Mean SP	S8 (140-DAS)			Mean SP	S9 (160-DAS)			Mean SP	Mean T	Mean P		
	T1	T2	T3		T1	T2	T3		T1	T2	T3		T1	T2	T3					
P_1	-2.76	-3.65	-2.89	-3.1	-2.00	-2.66	-2.08	-2.24	-1.77	-2.01	-1.86	-1.88	-1.01	-1.84	-1.14	-1.33	-4.33	-4.27		
P_2	-2.87	-4.78	-3.33	-3.7	-2.18	-3.3	-2.78	-2.75	-1.78	-2.98	-1.87	-2.21	-1.21	-2.21	-1.17	-1.53	-5.89	-4.90		
P_3	-3.45	-5.95	-4.98	-4.8	-2.98	-4.98	-3.45	-3.80	-2.11	-3.83	-2.87	-2.93	-1.78	-2.78	-1.85	-2.13	-4.81	-5.86		
Mean ST	-3.00	-4.80	-3.70	-3.9	-2.38	-3.64	-2.77	-2.93	-1.89	-2.94	-2.20	-2.34	-1.33	-2.28	-1.39	-1.67				

Table 10: Effect of different packaging materials and ethylene inhibitors/absorbers on Instrumental Colour (b*) of Golden Delicious apples under 160 days of ambient storage

	S1 (0-DAS)			Mean SP	S2 (20-DAS)			Mean SP	S3 (40-DAS)			Mean SP	S4 (60-DAS)			Mean SP	S5 (80-DAS)			Mean SP
	T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3	
P_1	37.09	37.09	37.09	37.09	46.09	43.43	45.05	44.85	50.36	46.11	47.60	48.02	53.32	50.98	51.29	51.86	56.28	52.86	53.98	54.37
P_2	37.09	37.09	37.09	37.09	44.09	42.35	43.68	43.37	49.2	45.71	47.76	47.55	53.18	48.60	51.67	51.15	54.17	50.29	53.57	52.67
P_3	37.09	37.09	37.09	37.09	43.80	39.85	41.63	41.76	47.13	41.15	45.06	44.44	50.07	45.44	48.43	47.98	53.01	47.73	51.81	50.85
Mean ST	37.09	37.09	37.09	37.09	44.66	41.88	43.45	43.33	48.90	44.32	46.81	46.68	52.19	48.34	50.46	50.33	54.49	50.29	53.12	52.63
	S6 (100-DAS)			Mean SP	S7 (120-DAS)			Mean SP	S8 (140-DAS)			Mean SP	S9 (160-DAS)			Mean SP	Mean T	Mean P		
	T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3					
P_1	59.32	54.78	57.65	57.25	60.34	56.87	59.12	58.77	61.37	59.46	60.43	60.42	62.32	60.95	61.92	61.73	52.49	52.70		
P_2	56.54	53.56	55.65	55.25	57.77	55.55	57.34	56.88	59.17	58.28	58.99	58.81	61.27	59.35	60.34	60.32	49.25	51.43		
P_3	54.74	48.97	53.66	52.45	55.45	50.13	54.66	53.41	57.23	52.12	56.21	55.18	59.94	53.96	57.19	57.03	51.30	48.91		
Mean ST	56.87	52.44	55.65	54.99	57.85	54.18	57.04	56.36	59.26	56.62	58.32	58.13	61.18	58.09	59.82	59.69				

Table 11: Effect of different packaging materials and ethylene inhibitors /absorbers on Instrumental Colour (ΔE) of Golden Delicious apples under 160 days of ambient storage

	S1 (0-DAS)			Mean SP	S2 (20-DAS)			Mean SP	S3 (40-DAS)			Mean SP	S4 (60-DAS)			Mean SP	S5 (80-DAS)			Mean SP
	T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3	
P_1	12.05	12.05	12.05	12.05	16.83	15.65	16.01	16.27	20.84	16.91	17.51	18.42	21.39	19.67	21.32	20.79	23.93	20.56	23.28	22.59
P_2	12.05	12.05	12.05	12.05	15.57	14.30	14.92	14.32	20.46	16.73	19.36	18.85	21.93	18.20	22.01	20.71	21.72	18.31	21.95	20.66
P_3	12.05	12.05	12.05	12.05	16.40	13.01	14.38	15.10	19.08	14.82	17.73	17.21	21.72	18.14	20.73	20.20	23.67	20.60	23.25	22.51
Mean ST	12.05	12.05	12.05	12.05	16.16	14.09	14.60	15.23	20.13	16.15	18.20	18.16	21.68	18.67	21.35	20.57	23.11	19.82	22.83	21.92
	S6 (100-DAS)			Mean SP	S7 (120-DAS)			Mean SP	S8 (140-DAS)			Mean SP	S9 (160-DAS)			Mean SP	Mean T	Mean P		
	T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3		T_1	T_2	T_3					
P_1	26.51	22.88	26.39	25.26	26.88	25.10	27.89	26.62	24.84	27.61	26.50	26.32	25.75	27.54	26.90	26.73	21.60	21.66		
P_2	24.22	21.64	23.38	23.08	26.09	23.23	25.31	24.88	25.05	26.13	25.49	25.56	25.70	26.98	25.93	26.20	19.73	20.76		
P_3	24.61	20.67	24.32	23.20	24.02	21.90	25.75	23.89	24.33	22.39	27.09	24.60	25.72	23.60	27.09	25.47	21.50	20.41		
Mean ST	25.11	21.73	24.70	23.85	25.66	23.41	26.32	25.13	24.74	25.38	26.36	25.49	25.72	26.04	26.64	26.13				

Conclusion

The study findings suggest that combining shrink wrap packaging with post-harvest application of 1-MCP proved most effective in extending the shelf life of Golden Delicious apples, with shrink wrap packaging combined with $KMnO_4$ following closely behind. When used alongside shrink wrap packaging, 1-MCP notably retain starch, Sugars (Total, Reducing and non- reducing sugars), Vitamin C, Carotenoids, Pectin and Instrumental Color. Consequently, after 160 days of ambient storage, the treated fruits retained fair to high quality, successfully preserving their key characteristics, minimizing post-harvest losses, and prolonging their shelf life.

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