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Development of eco-friendly low-cost package for shelf-life enhancement of fruits and vegetable

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Abstract
Perishable products like fruits and vegetables necessitate optimal storage conditions in order to increase their shelf life. Improper packaging and storage are the main factors which influence on increased post-harvest losses in fruits and vegetables. Small and marginal farmers are unable to access for modern storage units so it results to 40% of agricultural production waste. To resolve this issue, an eco-friendly low-cost package was developed. This package uses clay to coat the carton boxes, which uses the selective permeability and lowers the respiration and transpiration losses of fruits and vegetables stored in the container. To determine the effectiveness and efficiency of the coated carton boxes were analysed by employing CO_2 (30g) O_2 (5g) absorbers, and various quantities (5-15g) of $KMnO_4$. The package without any absorbers had achieved maximum storage shelf life compared to other packages containing gas observer. This is mainly due to reduced respiration and transpiration losses from the fruits due to selective permeability of clay coated carton box.

Keywords: Green package, green energy, eco-friendly, food package

Introduction
Fruits and vegetables, by their very nature, are perishable (Chitranshi *et al*., 2020) [7]. After harvest, perishable items like vegetables and fruits continue to metabolize and breathe, which means the oxygen present in the atmosphere is used up, resulting in heat, CO_2, moisture, and possibly ethylene gas. (Keshri *et al*., 2019, Mathur & Chugh, 2020) [17, 20]. It's also been reported that due to a lack of packing, transportation, and storage facilities, perishable goods lose up to 50% of their market after harvest (Elik *et al*., 2019, Khalid *et al*., 2020) [9, 18]. The loss ranged from 4.58 percent to 12.44 percent for vegetables, including 12.44 percent for tomato, 9.56 percent for cauliflower, 9.37 percent for cabbage, 8.20 percent for onion and 7.32 percent for potatoes. (Tiwari *et al*., 2020) [28]
Tomatoes (*Solanum lycopersicum*) have short shelf life due to a number of factors which includes a thin peel, a high respiration rate, low firmness, and a high-water content (Yadav *et al*., 2022) [32]. It has a shelf life of 4 to 9 days at room temperature. (Viswanathan *et al*., 1998) [30]. There is a considerable amount of tomato not reaching consumers, because of postharvest losses (Abera *et al*., 2020) [1]. Fresh fruits and vegetables, including tomatoes, will lose 5 to 25% of their market after harvest in developed countries, and 20 to 50% in developing countries. (Tiwari *et al*., 2020) [28].
Edible coating is one of the important preservation technique for controlling the permeability of gases which influence on biochemical reaction inside the fruits. (Hanumantharaju *et al*., 2019, Hanumantharaju *et al*., 2020) [12, 13]. Still edible coating won't have full control over the fruits biochemical reaction due to temperature variation around the atmosphere. The temperature directly impacts tomato quality as it directly impacts on transpiration and respiration losses (Al-Dairi *et al*., 2021) [2]. Maintaining the quality of fresh produce in the whole supply chain requires the proper control of temperature conditions (Arah *et al*., 2015) [4]. Tomato colour, firmness, and flavor are all impacted by temperature (Verheul *et al*., 2015) [29]. The temperature is directly related to the rate of losses associated with tomatoes (Jahan *et al*., 2021) [14] High temperatures can hasten deterioration because they increase transpiration, respiration and ethylene production rates. (Benichou *et al*., 2018) [5]
Ethylene is a gas that is naturally produced by fresh produce and can have a negative effect on product quality, nutrition, and marketability (Amit *et al*., 2017) [3]. As a result, several efforts have been made to slow the rate of ethylene gas induced deterioration of fresh produce (Cao *et al*., 2015) [6]. Potassium permanganate ($KMnO_4$) has been the most often utilized ingredient to

reduce ethylene content in packing headspace due to its cost-effectiveness and ease (Gaikwad *et al*., 2017) [11]. Under the appropriate environment, ethylene biosynthesis from fresh produce could speed up ripening and shorten postharvest life (Fagundes *et al*., 2015) [10]. Purple colored potassium permanganate ($KMnO_4$) oxidizes the ethylene, producing either ethylene glycol or acetic acid, which is further oxidised to CO_2 and H_2O in the presence of more permanganate, along with dark brown manganese oxide (MnO_2) (Yadav, 2020) [33]. The generation of water and CO_2 results from the oxidation of ethylene by $KMnO_4$. As a result, it can be used as a postharvest anti-ethylene component to help perishable fruits last longer. (Sujayasree and Falsludeen 2017) [26]

The clay coated chambers acts like a selective permeable barrier so that excess O_2 and ethylene inside the chamber permeated to outside and lowers the respiration and senescence by maintaining proper CO_2, O_2 and ethylene concentration, while reducing water loss without speeding up decay (Khuntia *et al*., 2022) [19].

This research intends to develop an eco-friendly low-cost package for fruit and vegetable with an objective of extending the shelf life of fruits and vegetables stored/packed under the developed package.

Materials and Methodology

Tomatos were (*Solanum lycopersicum var. lycopersicum*) was obtained from the local farmer field (Bangalore rural area). Physiologically matured tomatoes were selected and harvested in the early morning from a field. The carton boxes were bought from a carton box manufacturer in Seegehalli, Bengaluru, Karnataka and boxes were having length-17.5 cm, width-12.7 cm, height-10.68 cm and thickness-4mm). Clay dough is prepared by kneading 1kg of 0.005mm particle size clay particles with 300 ml water and 20g 0.05mm straw powder (for increasing the permeation). Clay and straw used for the clay dough preparation is shown in the figure 1. Clay dough is roughly coated to the carton box by manually. After coating, coated boxes were left for drying under shade for 24hours and the average thickness of the clay-covered box was measured to be 4.5mm.

Fig 1: Clay and straw used for the preparation of clay coated carton boxes

In this experimental setup 4 boxes were selected for storing the 1 kg tomatoes. Boxes were labelled as 1, 2, 3, 4 and variation of gas absorbers in the box is mentioned in the table 1. Physicochemical properties of stored tomatoes were analyzed on 5 days interval. Experimental setup is shown in the figure 2.

Table 1: Details of scrubber/absorbers provided in the experimental setup

Control	1st box	2nd box	3rd box	4th box
Open atmospheric condition	without any observers	5g of $KMnO_4$ + 30g sachet CO_2 absorber + 5g of 0_2 absorber	10g of $KMnO_4$ + 30g sachet CO_2 absorber + 5g of 0_2 absorber	15g of $KMnO_4$ + 30g of CO_2 absorber + 5g of 0_2 absorber

(2a) (2b) (2c)

Fig 2: Experimental setup (a) Clay coated carton boxes (b) Physiologically matured tomatoes (c) Experimental setup

Total soluble solids (TSS), Titratable acidity, Maturity index, Taste index, Ascorbic acid, Total carotene, and lycopene content were the physicochemical tests used to examine the qualities of tomatoes.

Total Soluble Solids (TSS)

The total soluble solid was determined by Milwaukee MA871 refractometer digital. The results were represented in °Brix% with temperature of the environment (Kaur *et al*., 2022) [16]

Titratable acidity (TA)

The titratable acidity (TA) of the samples was determined by homogenizing them with distilled water and titrating against 0.1 N NaOH until they reach a pH of 8.1. The results were calculated using the formula below and expressed as citric acid content percentages. (Dobrin, A., *et al.* (2019)) [8]

$$\text{Percent of titratable acidity} = \frac{V \times N \times 100 \times 0.0064}{m} \quad \ldots (1)$$

Where,

N - Normality of NaOH, 0.0064-Conversion factor for citric acid.

V - Volume of NaOH used (mL).

m - Mass of tomato sample used (g).

Maturity index (MI)

The maturity index of tomatoes was calculated with equation (Murariu *et al*., 2021) (4)

$$MI = \frac{°\text{Brix of sample}}{\text{titratable acidity}} \quad \ldots (2)$$

Ascorbic acid (AA)

The 2,6-dichlorophenolindophenol method was used to measure the ascorbic acid (AA) content of the tomato (AOAC, 1970).

Results and Discussion

The tomatoes under normal atmospheric condition have a shelf life of 7 days (Misra *et al.*, 2014) [21]. Hence control sample was kept to compare the shelf life of tomatoes stored in the clay coated carton boxes. Weight loss of tomatoes and weight of O_2, CO_2 and ethylene scrubbers on initial and final day (15th day) is tabulated in the table 2.

Table 2: Weight of the sachets placed inside the box from 1st to 15th day of experiment

	Weight Loss	$KMNO_4$ sachet			CO_2 sachet			O_2 sachet		
		Initial wt. (g)	Final wt.(g)	Increased wt.(g)	Initial wt. (g)	Final wt.(g)	Increased wt.(g)	Initial wt. (g)	Final wt.(g)	Increased wt.(g)
Control	60g	---	---	---	---	---	--	---	----	--
Box 1	36g	---	---	---	---	---	--	---	----	--
Box 2	46g	5g	6.59	1.591 g	30g	30.74	0.747g	5g	6.16	1.16
Box 3	78g	10g	11.55	1.55 g	30g	31.34	1.341	5g	6.623	1.623
Box 4	101g	15g	16.67	1.672 g	30g	31.40	1.408	5g	7.235	2.235

The weight loss of tomatoes held at room temperature was much greater than that of tomatoes placed in a clay-coated box-1. (Javanmardi & Kubota 2006) [15]. The weight loss in the tomatoes mainly due to the presence of respiration and transpiration process which will reduce the moisture present in the food product. Ethylene, CO_2 and O_2 absorbers were shown to be gained weight due to absorption of gas.

Weight loss

Sachets placed inside the box were weighed on 1st and 15th day and data is presented in the table 2. There is a little bit increase in CO_2 and O_2 absorber sachets in the clay coated boxes. Weight loss in the box 3 and 4 is greater than control due to a higher oxygen scrubber which absorb more oxygen and it might have triggered anaerobic reaction.

Total Soluble Solids (TSS)

TSS is one of the most important quality factors for most of fruit. In the present study, the TSS content of tomato varied significantly in different storage conditions. It was found that boxes without any ES, CO_2 and O_2 absorbers (box 1) is lower °Brix values of 2.8, 3.1, 3.2 and 3.4 on the day of 1st, 5th, 10th, and 15th day respectively and TSS values are represented in the figure 3. TSS increased gradually with the advancement of ripening process. Winsor *et al*., (1962) also reported similar trend of results related to TSS of fruits. Gradual increase in TSS content during advancing stages of ripening and storage which was possibly due to hydrolysis of starch into sugar.

Storage conditions were found to have significant effects on change in TSS content of tomato on 1st, 5th and 10th day of storage. The highest quantity of TSS content (4.2 °Brix) was recorded in box 4 treatment while it was lowest (3.4°Brix) in box 1 on 15th day storage.

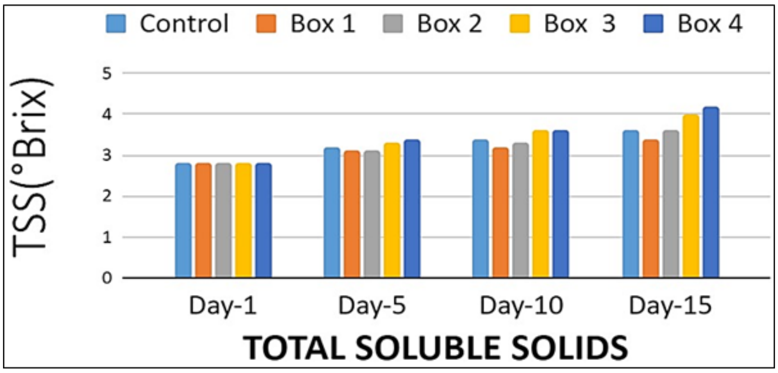

Fig 3: Total Soluble Solids

Total titratable acidity (TA)

Citric and malic acids are primarily responsible for the sour flavor of tomatoes. Due to the presence of glutamic acid, the most abundant free amino acid in tomatoes, free amino acids may have a taste-enhancement or buffering effect. The term sourness' is closely related to the term 'titratable acidity.' Figure 4 depicts that titratable acidity was highest in the initial days of storage and gradually decreased in all the samples. Box 1 has significantly higher TA values of 0.576, 0.528, 0.498, and 0.428 g/ml on the day of 1, 5, 10, and 15 respectively (Fig 4). Acidity loss has been linked to quality loss during postharvest storage of tomatoes, and when combined with soluble solids concentration, can influence customer acceptability (Zapata *et al*., 2008) [34].

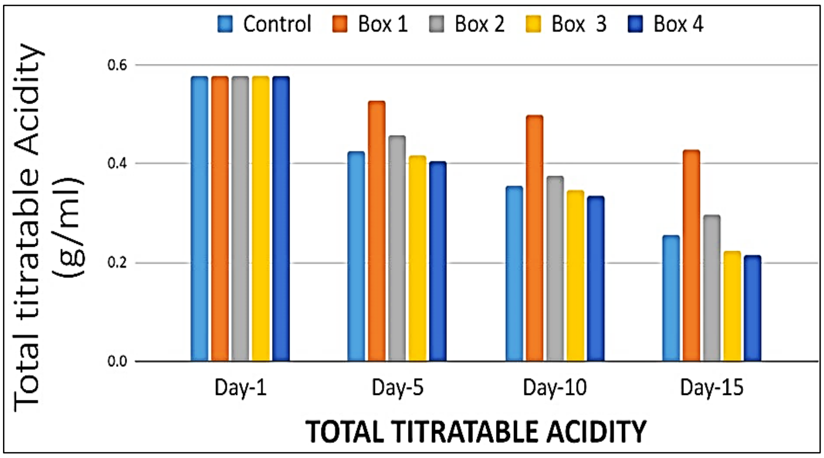

Fig 4: Total Titratable Acidity

Maturity index

Maturity index correlate the tomato harvest time based on fruitage, diameter, and color parameters. In addition physicochemical and nutritional parameters such as total soluble solids (TSS), total titratable acidity (TTA) and total soluble solids (TSS) are the main deciding factors for maturity index (Okiror., *et al*. 2017) [23]. From the Fig 5 it was observed that maturity index increased with storage days and it was lies in between 4.8 to 19.2. However, box 1 has a lower value of 7.943 on 15th days. According to Saleem *et al*. (2020) [25], maturity index increases with increased storage days mainly due to increase in the ration of total soluble solids to titratable acidity.

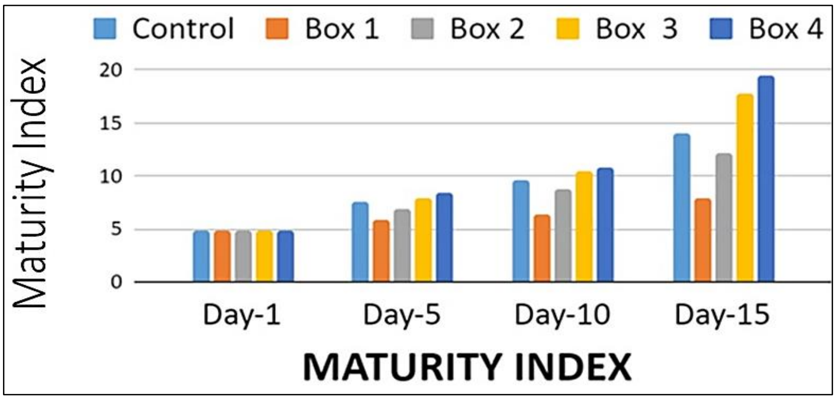

Fig 5: Maturity Index

Ascorbic acid (AA)

One of the most essential nutritional value indicators in fruits and vegetables is ascorbic acid. The concentration of ascorbic acid in this investigation varies. From the figure 6 it was observed that the ascorbic acid concentration started decreasing as the days passed. High ascorbic acid concentration (0.52, 0.49, 0.34, 0.25 g/100g with respective days) is interpreted in Box 1 (Fig 7). When compared to fresh market tomatoes, processed tomatoes exhibited higher ascorbic acid concentration after 20 days of storage. According to Tigist *et al*. (2013) [27], during the complete ripening stage, there was a general tendency of increasing AA content, followed by a decline. This tendency was consistent with prior findings that AA content rose with maturity (Toor and Savage 2006) and the findings here back up this theory (Tigist *et al*., 2013) [27].

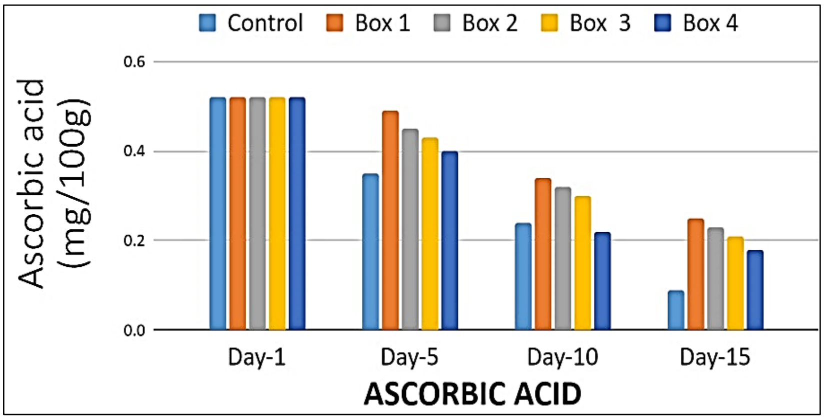

Fig 6: Ascorbic Acid

Conclusion

Clay coating acts like a semipermeable membrane for cooling and also acts as an ethylene scavenger (Ribeiro *et al*., 2021) [24] which helps in extending shelf life of produce. Paddy Straw was also added to clay for increasing the permeability. This package had shown extended shelf life of tomatoes when compared to samples kept in an outside environment. There was a significant effect ($P \leq 0.034$) on the quality attributes and most of the physicochemical parameters of tomato by storage conditions of clay coated carton boxes and time. Tomatoes stored in clay coated boxes with paddy straw keep the produce fresh throughout the storage period and reported to have higher total soluble solids, acidity, and ascorbic acid levels as storage time progressed. Boxes with ES and MS had a decent effect when compared to ambient storage conditions, while Box without ES and MS had a bigger impact. Hence it was more successful in keeping the quality of the stored horticultural output. This package had an extended shelf of 4 days when compared to samples kept in an outside environment. Modelling by optimizing gas permeability would be the future of this effort.

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