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Physiological Changes in Okra (*Abelmoschus esculentus* L.) by Postharvest Application with Hexanal Containing Aqueous Formulations

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aim: Okra is a vegetable that holds a significant share in both domestic and export markets, but it is prone to desiccation and fungal spoilage, leading to a short shelf life. A laboratory study was undertaken to determine the effects of hexanal containing aqueous formulation to improve the shelf life of okra with the objective to maintain the best quality of pods for end consumer acceptance.

Study Design: Factorial Completely Randomized Design was followed with three replications.

Place and Duration of Study: The study was conducted in laboratory conditions, Department of Vegetable Science, Horticultural College and Research Institute, Coimbatore during 2021-2022

Methodology: In this study, TNAU released nanoformulation– TNAU FRUITY FRESH – ENHANCED FRESHNESS FORMULATION consisting of 2% Hexanal, 10% Formulation ingredients, 88% Deionized filler. and hexanal was used at varying concentrations for imposing treatments on freshly harvested, uniform sized undamaged tender pods of bhendi hybrid COBh H4 (TNAU released hybrid) using spray and dip methods under ambient and cold storage conditions and physiological parameters were assessed.

Results: As per the investigation, 2% Enhanced Freshness Formulation using dip method in cold storage conditions slower the physiological loss in weight, preserves the L*, a*, b* value, extend the shelf life and preserved the quality for consumer acceptance during storage 9 days as compared to control.

Conclusion: The study gave the knowledge of hexanal containing aqueous formulation and their effectiveness to use as post-harvest technology tool for okra.

Keywords: Okra; nanoformulation; post-harvest; enhanced freshness formulation; hexanal.

1. INTRODUCTION

Okra (*Abelmoschus esculentus* (L.) Moench) is most the popular vegetable throughout the world for its delicious and nutritious edible green pods. Trade in okra has immense potential as a major foreign exchange earning crop, accounting for about 72.9% of the India's export of fresh vegetables excluding potato, onion, garlic etc. Kodandaram et al*.,* [1]. For export purpose, the quality criterion for okra pods should be green, tender, 4–5 ridged and approximately 6–8 cm in length Singh & Pandey, [2]. Generally, okra is harvested without following any safety measures resulting in mechanical injuries to the ridges of pods which lead to darkening of ridges, shriveled pods, mould growth and other storage diseases Singh & Pandey, [2]. Postharvest loss of okra ranges from 50 to 72%. In the recent past, some of our country's okra export consignments have been rejected at the destination because of blackening of ridges, shriveling of pods and development of moulds. Therefore, to maintain their high quality from harvesting to the entire supply chain and to predict the acceptability of the final product, it is important to study the post-harvest storage operations.

The challenges associated with postharvest storage of fruits and vegetables are their continuous metabolism and the resulting deterioration in nutritional content, flavor, and appearance. To address these issues, various methods have been employed, including low temperature storage, modified atmospheric storage, irradiation, and coating. Edible coating, a technology gaining popularity, involves applying a protective layer to minimize water loss, gaseous exchange, and oxidation processes. This method is environmentally friendly and can incorporate active ingredients to enhance safety and quality.

In the context of edible coatings, nanoemulsion-based solutions have been proposed to extend the shelf life of horticultural produce. These coatings create a semitransparent layer on the surface of fruits and vegetables, reducing respiration, transpiration rates, oxidative reactions, and pathogenic growth. This approach, while enhancing shelf life, also contributes to environmental sustainability due to its consumption with the product and the absence of disposable packaging. G. Gundewadi et al*.,* [3].

However, limited research exists on enhancing the shelf life of vegetables like okra. Traditional methods use synthetic surfactants to enable nanoemulsion formation, but there's a growing demand for organic and environmentally friendly alternatives. The advantages of nanoparticle-based edible films over traditional methods include their consumption with products, reducing environmental pollution, use of renewable ingredients, and improved degradation rates. These films can even enhance the sensory properties of packaged foods.

Given this background, the present investigation was aimed to develop Enhanced Freshness formulation with an optimal concentration to preserve highly perishable okra. The goal was to improve quality, retain volatile flavor compounds, prevent chlorophyll loss, inhibit free radical accumulation, and offer protection against microbial activity. The study is likely to contribute to the development of effective and sustainable methods for extending the shelf life of okra and potentially other vegetables.

2. MATERIALS AND METHODS

The present investigation was carried out in the analytical laboratory, Department of Vegetable Science, Horticultural College & Research Institute, Coimbatore during the period 2021-22.

Sample Selection: The study focused on the bhendi hybrid COBh H4, which is a variety released by the Tamil Nadu Agricultural University (TNAU). Only bhendi pods that were uniformly sized, mature, and undamaged were chosen to ensure consistent baseline conditions for the study. The selected bhendi pods were transported from the field to the laboratory shortly after harvesting, within a few hours.

Imposing Treatments: The study involved subjecting the selected bhendi pods to specific treatments. A nanoformulation developed by Tamil Nadu Agricultural University (TNAU) called **"TNAU FRUITY FRESH – ENHANCED FRESHNESS FORMULATION."** This formulation is designed to enhance the freshness and preservation of fruits. Here's a breakdown of the key components and their characteristics:

Composition of TNAU FRUITY FRESH: Hexanal compound makes up 2% of the formulation. Hexanal, also known as hexanaldehyde or caproaldehyde, is an alkyl aldehyde and is described as potentially useful as a natural extract to prevent fruit spoilage. Its properties could contribute to slowing down the deterioration of fruits. Its molecular weight (MW) is 100.16 g/mol. Formulation Ingredients makes up 10% of the formulation. Deionized Filler makes up 88% of the formulation. A deionized filler is a substance that likely provides bulk to the formulation without introducing ions.

Preparation of Nanoformulation:

- **Hexanal Formulation:**
  - Three different hexanal formulations were prepared, using 10 ml, 20 ml, and 30 ml of hexanal, respectively.
  - Each amount of hexanal was taken in a separate standard volumetric flask with a capacity of 100 ml.
- **Addition of Tween 80 and Ethanol:**
  - To each flask containing the hexanal, 10% (v/v) Tween 80 dissolved in ethanol was added.
  - Tween 80 is a surfactant that aids in stabilizing the emulsion by reducing the interfacial tension between the immiscible liquids.
- **Volume Adjustment:**
  - After adding Tween 80, the volume in each flask is brought up to 100 ml using the appropriate solvent (likely ethanol, considering its use in dissolving Tween 80).
- **Preparation of Nanoemulsions:**
  - The resulting mixtures in each flask form nanoemulsions of hexanal.
  - These nanoemulsions are stabilized formulations where hexanal is dispersed as tiny droplets in the mixture, forming a stable and homogenous mixture at the nanometer scale.
- **Concentration of Nanoemulsions:**
  - The different hexanal formulations result in different concentrations of nanoemulsions. The concentrations are 1%, 2%, and 3%, respectively, based on the amounts of hexanal used in the formulations.

The preparation of nanoemulsions with different concentrations of hexanal, along with the use of Tween 80 and ethanol as stabilizing agents, suggests a controlled and systematic approach to enhancing the effectiveness of hexanal for post-harvest preservation of the produce.

2.1 Experimental Details

Overview of experimental setup: Okra fruits were treated individually with the formulation solutions. After treatment, the okra fruits were dried to remove excess solution from the surface. Ten treated okra fruits from each treatment group were placed together. These groups of 10 fruits per treatment were then transferred into a carton box. Uncoated okra fruits, which did not receive any treatment, served as the absolute control group for comparison. The grouped okra fruits,

Chart 1. Analysis performed under given constant sections

Days	3rd		5th		7th		9th	
Storage	**Ambient**	**Cold**	**Ambient**	**Cold**	**Ambient**	**Cold**	**Ambient**	**Cold**
	Experimental Design			**2 FCRD**				
	Factor A	**Treatment(T)**	T1	Absolute control				
			T2	Control (Water)				
			T3	1% Enhanced Freshness Formulation				
			T4	2% Enhanced Freshness Formulation				
			T5	3% Enhanced Freshness Formulation				
			T6	1% Hexanal				
			T7	2% Hexanal				
			T8	3% Hexanal				
	Factor B	**Method(M)**	M1	Spray				
			M2	Dip				
	Treatment combinations			8 X 2 = 16				
	Replications			3				

including the control group, were subjected to two different storage conditions:

- Ambient Storage: Fruits were stored in a carton box at an ambient temperature of 25°C.

Cold Storage: Fruits were stored in a separate carton box under cold storage conditions at 4°C and a relative humidity (RH) of 95%.

Each carton box contained 10 fruits per replication. Observations were recorded on alternate days, starting from the 3rd day of storage, until the point when the fruits became unfit for consumption. The primary goal of this experiment was to evaluate the effects of the treatment formulations on the preservation and quality of okra fruits during storage. By monitoring and recording the physiological changes over time, was aimed to gain insights into the factors that influence the shelf life of the fruits and identify the treatments that are most effective in maintaining their quality.

2.2 Physiological Attributes

2.2.1 Physiological loss in weight (PLW)

Sample fruits of okra were weighed from the third day of storage to the final stage of fruit when it became unfit for consumption. The physiological loss in weight was determined as described by A.O.A.C. (1975). The physiological loss in weight was determined by using the following formula and expressed as percentage.

PLW (%) = Initial fruit weight (g)-Fruit weight on the day of observation (g) / Initial fruit weight (g) ×100

2.2.2 Pod texture

The texture of pods was measured with the help of Texture Analyzer (Model TA-HDi make, stable Microsystems, UK) using 2 mm cylindrical stainless steel probe and results expressed in gram force.

2.2.3 Colour

Colour flex meter (Model: 45°/0°, M/s Hunter Lab, Reston, Virginia, USA) was used for measurement of colour. It works on the principle of collecting the light and measuring energy from the sample reflected across the entire visible spectrum. The meter uses filters and mathematical models rely on "standard observer curves" that define quantity of red, green, and blue primary lights required to match a series of colours across visible spectrum. The mathematical model used is called Hunter model (Hunter 1975). It provides reading in terms of L, a, and b. where L indicates whiteness and darkness. Chromatic portion of the solids is defined by: +a (red), -a (green), +b (yellow), and -b (blue). These data may be sensed from the sensor (colour flex 45°/0°) and it is supported with Universal software V 4.10 package. Colour meter is calibrated by fixing the defined colours like white and black tiles on the colour flex meter. Calibration is performed through necessary changes in sample.

2.2.4 Fungal decay

The first sign of okra deterioration was observed as a small wet lesion on pod, and then the entire pod coated with a greyish-white mass of mould. The okra pods were evaluated when incidence of decay occurred, calculated based on weight of pods showing symptoms of decay (D), and classified into four categories, including <10%, 10–25%, 25–50%, and >50% of decay occurrence. Percentage decay (%) was calculated on the basis of total weight of pods per plastic basket (TW), using:

$$Decay\ (\%) = \frac{D}{TW} \times 100$$

Incidence of decay was determined at the end of simulated storage.

2.2.5 Shelf life

Pods were harvested and kept both at room and cold storage temperature using spray and dip methods of treatments and visually observed until the consumption stage and it was recorded as number of days of shelf life.

2.3 Organoleptic Evaluation

According to Saberi et al*.,* [4] subjective sensory evaluation of data about the okra samples' can be done based on quality, taste, appearance, and overall acceptability. By using a standardized scale, the evaluation results can be quantified and analyzed to understand the preferences of the panelists for the different coating treatments and storage conditions.

3. RESULTS AND DISCUSSION

The physiological loss in weight (PLW) of okra pods increased during storage, irrespective of the imposed treatments (Table 1). Pods imposed treatments with 2% EFF using dip method recorded minimum PLW (11.31%) after 9 days of storage in cold conditions whereas in absolute control, PLW after 9 days of storage was 12.14% in cold storage condition of nine days of storage period. Under ambient condition, the lowest PLW was observed in the treatment T4, (2% EFF) using dip method with the value of 10.19% followed by the treatment T5 (3% EFF) using dip method with the value of 10.28%. Among the storage conditions, the fruits stored at cold storage conditions using dip method recorded the lowest PLW % in all the treatments compared to fruits stored at ambient condition. Weight loss is accompanied with change in texture and surface shriveling, loss of glossiness and loss of nutrients resulting in adverse effect on the quality and shelf life of fruits and vegetables. EFF treatment reduced the microbial load and moisture loss thus extends shelf life by reduce the weight and moisture loss. V. Premalakshmi et al*.,* [5]. The same finding was reported by Nasrin et al*.,* [6] in tomato fruits were dipped in 200ppm chlorine solution for 5 minutes. The hexanal treated fruits may be attributed to the thickening of cell wall as a consequence of lipoygenase inhibition. Biochemical changes induced after the application of the hexanal formulation may have helped preserve the membrane integrity and cell structure resulting in reduced catabolic process and quality losses. Tiwari and Paliyath, [7]. Through this study, it can be concluded that the coating acted as a barrier and consequently reduced water loss, respiration, ethylene and thereby improved membrane integrity and firmness of okra. These results are on expected lines as edible coatings act as deterrents against moisture, gases and solute movement, leading to decrease in rate of respiration, moisture transmission and oxidation associated reactions Baldwin et al*.,* [8]; Mannozzi et al*.,* [9]; Nawab et al*.,* [10].

3.1 Pod Texture

Pod texture is insignificant in the treatments imposed and do not much affect in the investigation process.

3.2 Colour

Appearance of vegetables, particularly green vegetables is the most important parameter governing their acceptability. Upon storage, besides shrivelling, darkening (browning) of ridges is a major problem in okra pods affecting their appearance (Dhall, Sharma, & Mahajan, 2011). Hunter colobur value L*, a*, b*. It is apparent from (Table 4) that colour coordinates L* (Lightness/Luminosity) was declined during storage and colour coordinates for a* (Greenness) and b* (Yellowness) increased significantly with storage of okra fruits. 2% EFF using dip method recorded maximum colour value L* (Luminosity/lightness) 44.9 while in untreated fruits luminosity was 29.0 stands minimum after 9 days of cold storage condition. However, minimum luminosity was recorded in fruits dip in hexanal formulations as their skin turn black. The data concerning colour a* value show that minimum value for greenness (-) and maximum value for redness (+). Colour coordinates for a* (Table 5) maintain in T4 (2% EFF) and T5 (3% EFF) treatments i.e. -9.8 and -9.1 respectively using dip methods in cold storage conditions. The data concerning colour b* value show that minimum value (-) for blueness and maximum value (+) for yellowness. It is clear from (Table 6) that T4 (2% EFF) showed maximum b* (19.12) and minimum value recorded in treatment with hexanal dip (T6, T7, and T8) on 9th day of storage period. Changes in colour intensity and quality are

Table 1. Effect of nanoformulations on physiological loss in weight (%) of "Bhendi hybrid COBh H4"

Days	**3rd**						**5th**						**7th**						**9th**					
Storage	**Ambient**			**Cold**			**Ambient**			**Cold**			**Ambient**			**Cold**			**Ambient**			**Cold**		
T	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**
	M_1	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**	
T_1	4.51	4.51	4.51	5.23	5.23	5.23	7.53	7.53	7.53	7.89	7.89	7.89	9.77	9.77	9.77	9.56	9.56	9.56	11.32	11.32	11.32	12.14	12.14	12.14
T_2	4.33	3.89	4.11	5.01	5.48	5.24	7.32	7.15	7.23	7.54	6.69	7.11	9.45	8.47	8.96	9.12	8.95	9.03	10.86	10.46	10.66	12.03	11.34	11.68
T_3	4.12	3.68	3.9	4.98	5.17	5.07	7.11	6.87	6.99	7.32	6.32	6.82	9.21	8.12	8.66	9.01	8.97	8.99	10.56	10.25	10.41	11.87	11.15	11.51
T_4	3.61	3.45	3.53	4.65	5.01	4.83	6.95	6.66	6.8	7.11	6.12	6.61	8.56	8.01	8.28	8.74	8.65	8.69	10.20	10.19	10.20	11.57	11.31	11.44
T_5	3.74	3.89	3.81	4.74	4.88	4.81	7.02	6.89	6.95	7.01	5.89	6.45	8.99	8.22	8.6	9.21	8.56	8.88	10.26	10.28	10.27	11.49	11.61	11.55
T_6	4.12	3.67	3.89	4.91	5.32	5.11	7.26	7.02	7.14	7.31	6.48	6.89	9.22	8.12	8.67	8.96	8.64	8.8	10.46	10.45	10.46	11.99	11.22	11.6
T_7	4.01	3.58	3.79	4.78	5.21	4.99	7.11	6.85	6.98	7.22	6.23	6.72	9.19	8.09	8.64	8.92	8.56	8.74	10.41	10.28	10.34	11.91	11.23	11.57
T_8	3.99	3.51	3.75	4.71	5.16	4.93	7.01	6.78	6.89	7.16	6.21	6.68	8.81	8.06	8.43	8.89	8.51	8.7	10.34	10.42	10.38	11.65	11.23	11.44
Mean	4.05	3.77	3.91	4.87	5.18	5.02	7.16	6.96	7.06	7.32	6.47	6.89	9.15	8.35	8.75	9.05	8.8	8.92	10.55	10.46	10.50	11.83	11.4	11.61

Days		3rd		5th		7th		9th	
Storage		**Ambient**	**Cold**	**Ambient**	**Cold**	**Ambient**	**Cold**	**Ambient**	**Cold**
Factors	**Variables**								
T	S.E.d	0.068	0.077	0.091	0.091	0.145	0.104	0.067	0.134
	CD (0.05)	0.139	0.158	0.187	0.186	0.298	0.213	0.137	0.274
M	S.E.d	0.034	0.039	0.046	0.045	0.073	0.052	0.033	0.067
	CD (0.05)	0.069	0.079	0.094	0.093	0.149	0.107	0.069	0.137
T X M	S.E.d	0.096	0.109	0.129	0.128	0.206	0.147	0.095	0.190
	CD (0.05)	0.197	0.223	0.255	0.263	0.421	0.293	0.194	0.388

Table 2. Effect of nanoformulations on pod texture (g-force) of "Bhendi hybrid COBh H4"

Days	3rd						5th						7th						9th					
Storage	**Ambient**			**Cold**			**Ambient**			**Cold**			**Ambient**			**Cold**			**Ambient**			**Cold**		
T	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**	**M**		**M**
	M_1	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**	
T_1	646.2	648.3	647.25	648.2	650.3	649.25	620.4	621.3	620.85	621.5	624.5	623.00	575.6	580.6	578.10	577.1	581.2	579.15	552.3	552.1	552.20	553.2	554.5	553.85
T_2	647.1	649.1	648.10	648.5	651.2	649.85	621.4	621.9	621.65	622.3	625.6	623.95	576.7	581.1	578.90	578.6	582.1	580.35	553.4	553.8	553.60	553.8	555.5	554.65
T_3	648.6	650.2	649.40	650.2	652.4	651.30	623.1	622.7	622.90	623.4	627.5	625.45	578.2	583.2	580.70	579.4	584.3	581.85	555.4	554.2	554.80	554.3	556.1	555.20
T_4	650.2	652.7	651.45	652.4	654.6	653.50	625.5	624.3	624.90	626.1	628.4	627.25	580.2	585.7	582.95	580.1	584.8	582.45	554.9	556.2	555.55	555.4	554.2	554.80
T_5	649.9	653.4	651.65	653.1	653.8	653.45	624.5	626.2	625.35	627.4	628.1	627.75	579.7	584.1	581.90	579.5	584.3	581.90	553.7	556.8	555.25	552.6	553.4	553.00
T_6	648.7	650.6	649.65	649.8	651.6	650.70	622.4	622.5	622.45	622.8	626.3	624.55	577.4	581.9	579.65	578.9	583.1	581.00	554.1	553.9	554.00	553.9	555.6	554.75
T_7	649.3	649.6	649.45	649.9	652.6	651.25	622.9	623.4	623.15	624.8	627.8	626.30	578.8	583.8	581.30	579.1	583.6	581.35	553.6	555.2	554.40	554.8	554.8	554.80
T_8	650.1	652.2	651.15	650.7	652.8	651.75	623.5	623.8	623.65	625.5	628.1	626.80	579.4	584.7	582.05	579.4	583.9	581.65	554.2	556.1	555.15	554.9	555.2	555.05
Mean	648.76	650.76	649.76	650.35	652.41	651.38	622.96	623.26	623.11	624.22	627.03	625.62	578.25	583.13	580.69	579.01	583.41	581.21	553.95	554.79	554.37	554.11	554.91	554.51

Days		**3rd**		**5th**		**7th**		**9th**	
Storage		**Ambient**	**Cold**	**Ambient**	**Cold**	**Ambient**	**Cold**	**Ambient**	**Cold**
Factors	**Variables**								
T	**S.E.d**	NS	NS	NS	NS	NS	NS	NS	NS
	CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
M	**S.E.d**	NS	NS	NS	NS	NS	NS	NS	NS
	CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
T X M	**S.E.d**	NS	NS	NS	NS	NS	NS	NS	NS
	CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Table 3. Effect of nanoformulations on color a* of "Bhendi hybrid COBh H4"

Days	3rd						5th					
Storage	**Ambient**			**Cold**			**Ambient**			**Cold**		
T	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**
	M_1	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**	
T_1	-9.6	-9.8	-9.70	-10.2	-10.4	-10.30	-7.2	-7.5	-7.35	-7.6	-7.9	-7.75
T_2	-10.4	-10.6	-10.50	-10.1	-10.7	-10.40	-9.5	-9.8	-9.65	-8.9	-10.2	-9.55
T_3	-13.1	-13.5	-13.30	-12.2	-12.5	-12.35	-10.8	-11.4	-11.10	-10.2	-11.1	-10.65
T_4	-13.6	-13.7	-13.65	-12.6	-12.8	-12.70	-11.2	-11.5	-11.35	-11.8	-12.1	-11.95
T_5	-12.3	-12.5	-12.40	-12.6	-12.8	-12.70	-10.9	-11.4	-11.15	-10.6	-11.5	-11.05
T_6	-10.6	-10.8	-10.70	-10.7	-11.1	-10.90	-9.4	-9.6	-9.50	-9.7	-10.2	-9.95
T_7	-12.2	-12.4	-12.30	-12.5	-12.7	-12.60	-11.3	-11.6	-11.45	-11.5	-11.8	-11.65
T_8	-11.2	-11.3	-11.25	-11.6	-11.7	-11.65	-10.1	-10.3	-10.20	-10.5	-10.7	-10.60
Mean	-11.62	-11.82	-11.72	-11.56	-11.83	-11.70	-10.05	-10.38	-10.21	-10.10	-10.68	-10.39

Days	7th						9th					
Storage	**Ambient**			**Cold**			**Ambient**			**Cold**		
T	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**
	M_1	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**	
T_1	-6.2	-6.5	-6.35	-6.6	-6.9	-6.75	-5.3	-5.5	-5.40	-5.7	-5.9	-5.80
T_2	-8.2	-8.4	-8.30	-8.5	-8.8	-8.65	-6.4	-6.6	-6.50	-6.7	-6.9	-6.80
T_3	-9.1	-9.4	-9.25	-9.8	-9.9	-9.85	-8.4	-8.6	-8.50	-8.5	-8.8	-8.65
T_4	-10.4	-10.6	-10.50	-10.5	-10.8	-10.65	-9.4	-9.7	-9.55	-9.6	-9.8	-9.70
T_5	-9.5	-9.7	-9.60	-10.1	-10.3	-10.20	-8.6	-8.8	-8.70	-8.6	-9.1	-8.85
T_6	-8.1	-8.3	-8.20	-8.5	-8.8	-8.65	-7.2	-7.4	-7.30	-7.5	-7.8	-7.65
T_7	-9.2	-9.4	-9.30	-9.6	-9.9	-9.75	-8.4	-8.6	-8.50	-8.7	-8.9	-8.80
T_8	-8.5	-8.7	-8.60	-8.8	-9.1	-8.95	-8.1	-8.3	-8.20	-8.3	-8.5	-8.40
Mean	-8.65	-8.87	-8.76	-9.05	-9.31	-9.18	-7.73	-7.94	-7.83	-7.95	-8.21	-8.08

Days		3		5		7		9	
Storage		**Ambient**	**Cold**	**Ambient**	**Cold**	**Ambient**	**Cold**	**Ambient**	**Cold**
Factors	**Variables**								
T	**S.E.d**	0.185	0.174	0.137	0.167	0.145	0.115	0.126	0.061
	CD (0.05)	0.379	0.356	0.28	0.341	0.297	0.235	0.258	0.126
M	**S.E.d**	0.093	0.872	0.068	0.083	0.072	0.057	0.063	0.123
	CD (0.05)	0.190	0.178	0.140	0.170	0.148	0.117	0.129	0.252
T X M	**S.E.d**	0.262	0.246	0.194	0.236	0.205	0.163	0.178	0.174
	CD (0.05)	0.536	0.504	0.397	0.482	0.420	0.333	0.365	0.357

Table 4. Effect of nanoformulations on color b* of "Bhendi hybrid COBh H4"

Days	3rd						5th						7th						9th					
Storage	**Ambient**			**Cold**			**Ambient**			**Cold**			**Ambient**			**Cold**			**Ambient**			**Cold**		
T	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**	**M**		**Mean**
	M_1	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**		**M_1**	**M_2**	
T_1	25.9	26.2	26.05	26.1	26.4	26.25	22.1	22.5	22.3	23.4	24.1	23.75	19.9	20.6	20.25	20.4	21.1	20.75	17.4	18.1	17.75	17.1	18.6	17.85
T_2	25.8	26.4	26.10	26.2	26.8	26.5	22.3	22.8	22.55	23.7	24.5	24.10	20.1	20.9	20.50	20.6	21.4	21.00	17.5	18.3	17.90	17.8	18.7	18.25
T_3	25.9	26.8	26.35	26.9	27.1	27.00	22.7	22.9	22.8	23.9	24.8	24.35	20.5	20.9	20.70	20.9	21.8	21.35	17.9	18.5	18.20	17.9	18.9	18.40
T_4	26.4	27.1	26.75	27.3	27.6	27.45	23.1	23.2	23.15	24.5	25.3	24.90	20.9	21.6	21.25	21.5	22.4	21.95	18.5	18.9	18.70	18.5	19.2	18.85
T_5	26.3	26.9	26.60	27.3	27.5	27.40	22.8	23.1	22.95	24.3	25.1	24.70	20.7	21.3	21.00	21.2	22.1	21.65	18.3	18.6	18.45	18.4	19.0	18.70
T_6	25.8	26.4	26.10	26.9	27.2	27.05	22.6	22.7	22.65	23.9	24.7	24.30	20.7	21.0	20.85	20.9	21.9	21.40	17.8	18.4	18.10	17.8	18.8	18.30
T_7	25.9	26.6	26.25	27.1	27.4	27.25	23.0	22.8	22.90	24.2	25.2	24.70	20.8	21.2	21.00	21.1	22.3	21.70	18.1	18.5	18.30	18.2	18.9	18.55
T_8	26.0	26.4	26.20	27.0	27.5	27.25	22.6	22.6	22.60	24.1	24.9	24.50	20.5	21.4	20.95	21.0	22.1	21.55	17.9	18.1	18.00	18.1	18.6	18.35
Mean	26.00	26.60	26.30	26.85	27.18	27.01	22.65	22.82	22.73	24.00	24.82	24.41	20.51	21.11	20.81	20.95	21.88	21.41	17.93	18.43	18.18	17.97	18.83	18.41

Days		**3rd**		**5th**		**7th**		**9th**	
Storage		**Ambient**	**Cold**	**Ambient**	**Cold**	**Ambient**	**Cold**	**Ambient**	**Cold**
Factors	**Variables**								
T	**S.E.d**	0.64	0.568	0.513	0.58	0.521	0.632	0.566	0.613
	CD (0.05)	1.307	1.160	1.049	1.185	1.065	1.291	1.156	1.252
M	**S.E.d**	0.320	0.284	0.256	0.290	0.260	0.316	0.282	0.306
	CD (0.05)	0.653	0.580	0.524	0.592	0.533	0.645	0.578	0.626
T X M	**S.E.d**	0.905	0.803	0.726	0.820	0.738	0.894	0.801	0.867
	CD (0.05)	1.848	1.641	1.484	1.676	1.507	1.825	1.636	1.770

Table 5. Effect of nanoformulations on L* value of "Bhendi hybrid COBh H4"

Days	3rd						5th						7th						9th					
Storage	Ambient			Cold			Ambient			Cold			Ambient			Cold			Ambient			Cold		
T	M		Mean	M		Mean	M		Mean	M		Mean	M		Mean	M		Mean	M		Mean	M		Mean
	M_1	M_2		M_1	M_2		M_1	M_2		M_1	M_2		M_1	M_2		M_1	M_2		M_1	M_2		M_1	M_2	
T_1	42.1	43.5	42.8	43.9	44.8	44.35	32.2	32.9	32.55	32.5	33.2	32.85	30.1	30.4	30.25	30.5	30.8	30.65	28.2	28.4	28.30	28.9	29.0	28.95
T_2	43.4	43.8	43.6	43.9	45.0	44.45	34.8	35.1	34.95	33.1	33.8	33.45	32.2	30.7	31.45	30.8	31.2	31.00	28.8	28.9	28.85	29.3	29.4	29.35
T_3	48.3	48.7	48.5	48.6	49.1	48.85	46.3	46.8	46.55	47.2	47.4	47.30	45.2	45.8	45.50	45.7	45.9	45.80	43.1	43.8	43.45	43.5	43.9	43.70
T_4	52.2	52.9	52.55	53.1	53.8	53.45	48.5	48.7	48.60	48.8	48.9	48.85	46.3	46.7	46.50	46.4	46.9	46.65	44.3	44.4	44.35	44.8	44.9	44.85
T_5	51.1	51.6	51.35	51.4	51.9	51.65	47.4	47.6	47.50	47.6	47.8	47.70	45.5	45.7	45.60	45.7	45.8	45.75	43.6	43.8	43.70	44.1	44.3	44.20
T_6	47.2	47.9	47.55	47.4	47.9	47.65	45.2	45.4	45.30	45.6	45.9	45.75	43.1	43.5	43.30	43.4	43.8	43.60	41.2	41.4	41.30	41.5	41.7	41.60
T_7	47.5	48.5	48.00	48.6	48.9	48.75	47.2	47.3	47.25	47.5	47.8	47.65	43.2	43.3	43.25	43.5	43.8	43.65	42.2	42.4	42.30	42.7	42.8	42.75
T_8	49.2	48.9	49.05	49.3	49.6	49.45	46.4	46.8	46.60	47.1	47.6	47.35	44.2	44.5	44.35	44.6	44.7	44.65	42.3	42.5	42.40	43.6	43.8	43.70
Mean	47.62	48.22	47.92	48.27	48.87	48.57	43.5	43.82	43.66	43.67	44.05	43.86	41.22	41.32	41.27	41.33	41.61	41.47	39.21	39.45	39.33	39.80	39.98	39.89

Days		3rd		5th		7th		9th	
Storage		Ambient	Cold	Ambient	Cold	Ambient	Cold	Ambient	Cold
Factors	Variables								
T	S.E.d	1.04	1.115	1.048	1.119	1.126	1.163	1.182	1.284
	CD (0.05)	2.124	2.277	2.14	2.285	2.300	2.375	2.414	2.623
M	S.E.d	0.52	0.557	0.524	0.559	0.563	0.581	0.591	0.642
	CD (0.05)	1.062	1.138	1.07	1.142	1.15	1.187	1.207	1.311
T X M	S.E.d	1.471	1.577	1.482	1.582	1.593	1.645	1.672	1.816
	CD (0.05)	3.004	3.221	3.027	3.232	3.254	3.359	3.415	3.709

Table 6. Fungal decay in different environmental conditions

Days	3rd						5th						7th						9th					
Storage	Ambient			Cold			Ambient			Cold			Ambient			Cold			Ambient			Cold		
T	M		Mean	M		Mean	M		Mean	M		Mean	M		Mean	M		Mean	M		Mean	M		Mean
	M_1	M_2		M_1	M_2		M_1	M_2		M_1	M_2		M_1	M_2		M_1	M_2		M_1	M_2		M_1	M_2	
T_1	0	0	0	0	0	0	0	0	0	0	0	0	8.5	7.5	8	7	6.5	6.75	0	0	0.00	0	0	0
T_2	0	0	0	0	0	0	0	0	0	0	0	0	7.5	6.8	7.15	6.5	6.2	6.35	0	0	0.00	0	0	0
T_3	0	0	0	0	0	0	0	0	0	0	0	0	2.5	2.1	2.3	1.5	1	1.25	5.3	4.9	5.10	0	0	0
T_4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5	2.1	2.30	2	1.5	1.75
T_5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.1	3.5	3.80	3.5	3	3.25
T_6	0	0	0	0	0	0	0	0	0	0	0	0	6.5	6	6.25	6.2	5.9	6.05	8.5	0	4.25	0	0	0
T_7	0	0	0	0	0	0	0	0	0	0	0	0	4.5	4.2	4.35	2.5	2.1	2.3	6.5	6.1	6.30	5.3	5.1	5.2
T_8	0	0	0	0	0	0	0	0	0	0	0	0	5.5	5.1	5.3	4.9	4.5	4.7	7.5	7	7.25	6.5	6	6.25
Mean	0	0	0	0	0	0	0	0	0	0	0	0	4.37	3.96	4.16	3.57	3.27	3.42	4.3	2.95	3.63	2.16	1.95	2.06

Days		3rd		5		7		9	
Storage		Ambient	Cold	Ambient	Cold	Ambient	Cold	Ambient	Cold
Factors	Variables								
T	S.E.d	0	0	0	0	0.096	0.08	0.075	0.063
	CD (0.05)	0	0	0	0	0.197	0.164	0.155	0.129
M	S.E.d	0	0	0	0	0.048	0.04	0.037	0.031
	CD (0.05)	0	0	0	0	0.098	0.082	0.077	0.064
T X M	S.E.d	0	0	0	0	0.136	0.113	0.107	0.089
	CD (0.05)	0	0	0	0	0.279	0.232	0.219	0.182

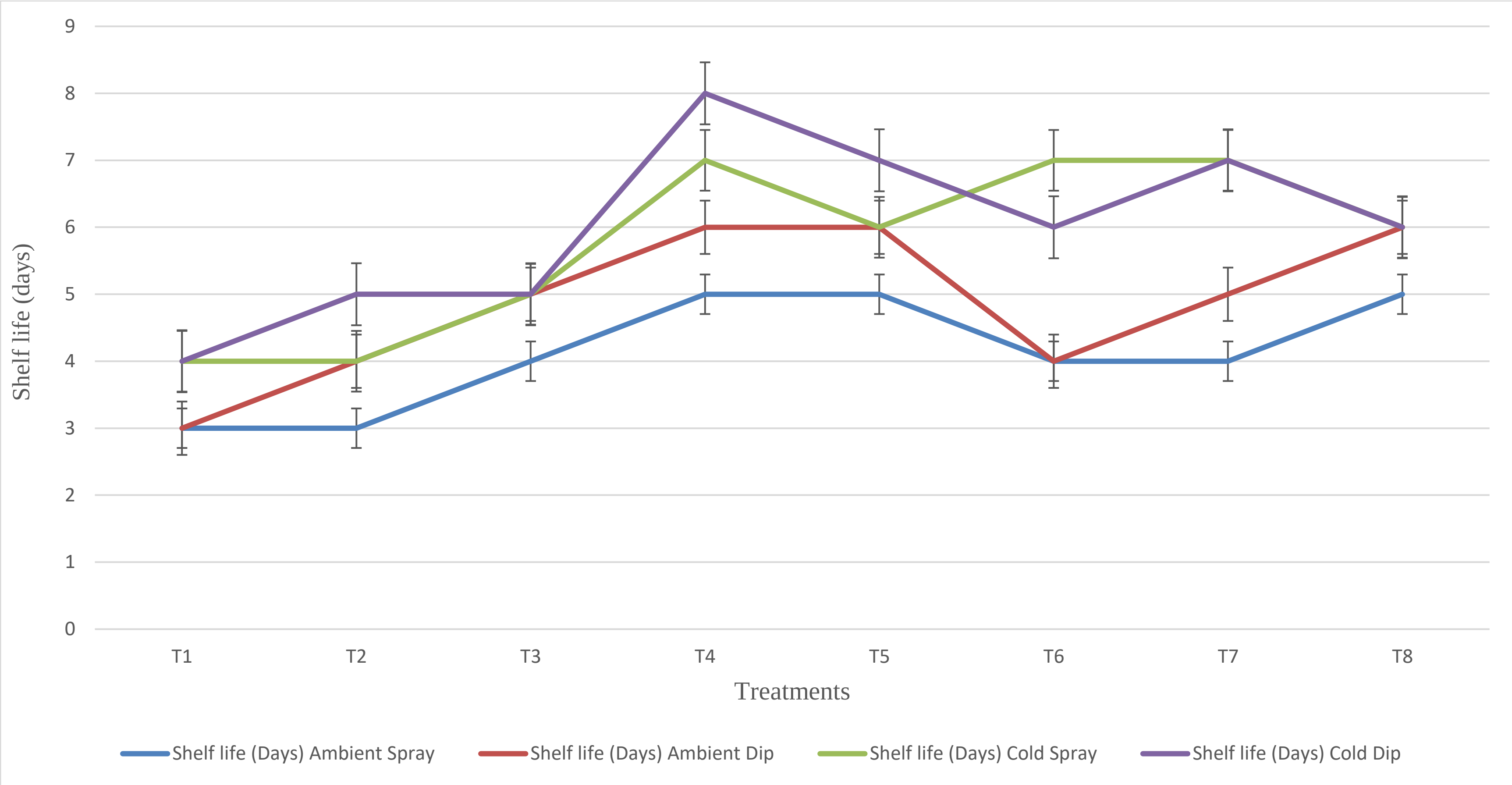

Fig. 1. Effect of nanoformulations on shelf life (days) of "Bhendi hybrid COBh H4

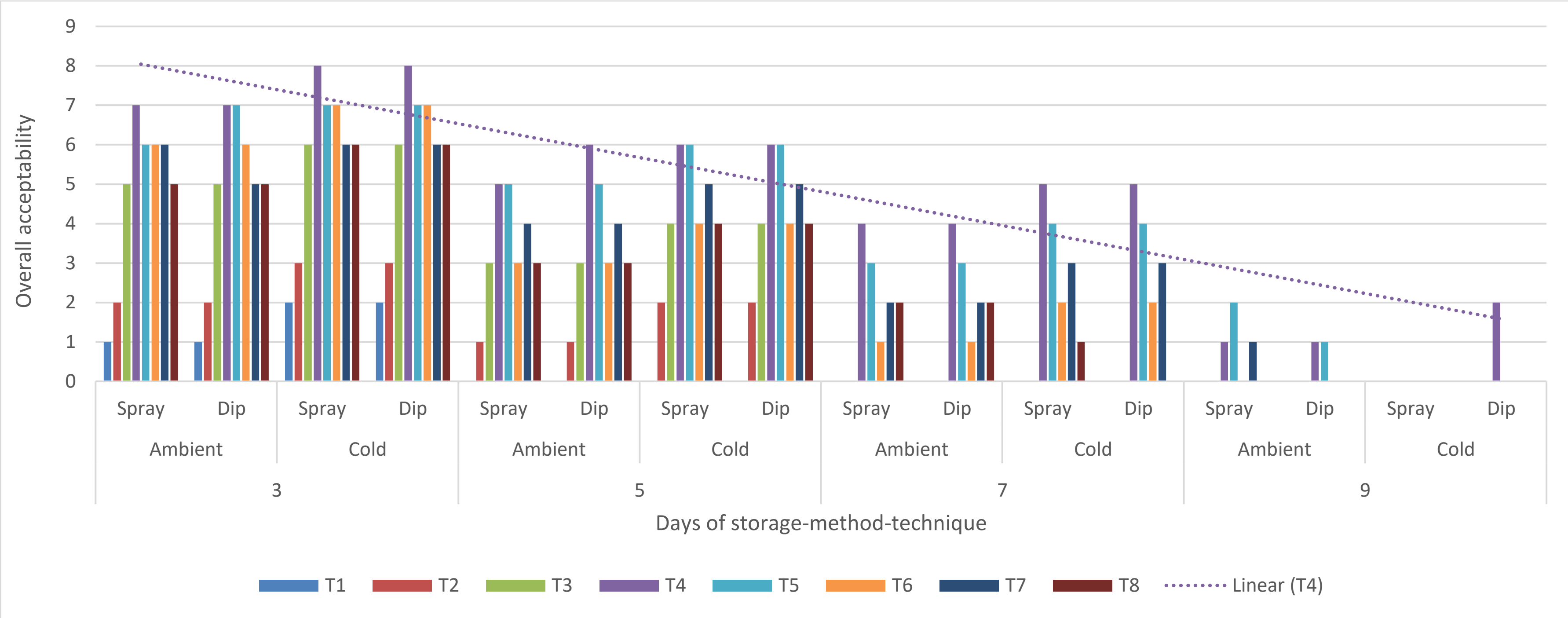

Fig. 2. Effect of nanoformulations on overall acceptability of "Bhendi hybrid COBh H4"

important indicators of maturity and quality for fresh tomatoes and development of red colour is considered as an index of maturity Lopez Camelo and Gomez, [11]. Effectiveness of EFF on slowing down senescence was also reflected in postharvest dip applications. Tomatoes dipped in EFF showed higher L values, hue angle, and reduced red colour intensity than control fruit during storage, suggesting a delay in ripening. Tiwari and Paliyath, [12]. Other investigations, the colour retention in hexanal treated samples may be attributed to the fact that hexanal reduced the rate of respiration which in turn resulted in reduced synthesis of ethylene. Similar estimates have been reported by Paliyah and Subramanian (2008), Ziaullah Sulaimankhil et al*.,* [13].

The data on rotting of pods revealed that pods treated with 2% EFF using dip method in cold storage recorded 1.75% of rotten fruits followed by 3% EFF had 3% rotten fruits till 9 days of storage. Okra samples were packaged in low density polyethylene films (LDPE) encased to chitosan-ZnO nanocomposites at room temperature (25°C). Chitosan-ZnO nanocomposite coatings have been shown in this study to inhibit microbial and fungal growth while also maintaining the quality of packed okra. As a result, a coating made of chitosan-ZnO nanocomposite can be used for active food packaging. The lesser percentage of fungal decay in treated okra than in untreated ones could be attributed to the fact that nanoformulation acted in providing a protective coating on the surface of pods resisting the entry of fungal pathogens. Similar results were obtained by El-Mogya et al*.,* [14].

The okra pods were visually observed for the quality during the storage period. The shelf life was assessed in terms of spoilage due to fungal invasion, wilting and shrinkage. Among the different treatments imposed, the treatment T4 (2% EFF) showed better shelf life till 9 days of cold storage using dip method and the least storage for observed in control 4 days. The pods dipped in hexanal solution remained fresher and brighter than the undipped ones which might be due to the fact dipping offered a protective layer in reducing rate of transpiration and also act as barrier in preventing loss of moisture content from its fruits. The results are in accordance with findings of Chemma et al*.,* [15], Venkatachalam et al*.,* [16], Hutchinson et al., [17] in tomato, banana and papaya.

Overall acceptability: The sensory quality of pods decreased at a slower rate for T4 (2% EFF) treatment as compared other treatments using dip method during cold storage. The overall sensory quality score was highest (5) upto 7 days for T4 pods whereas pods treated with T7 (2% hexanal) recorded the overall sensory score of 5 after 5 days of storage [18,19]. Thereafter there is loss in the sensory quality due to development of fibre over prolonged storage. Fibreness is not preferred in terms of consumer acceptance. Hence, the untreated pods were not accepted by the panelists due to the fibre. Similar results have been reported by Falade et al*.,* [20] and Arise et al*.,* [21].

Table 7. Shelf life

		Shelf life (Days)	
Storage		Ambient	Cold
Factors	Variables		
T	S.E.d	0.07	0.076
	CD (0.05)	0.143	0.155
M	S.E.d	0.035	0.038
	CD (0.05)	0.072	0.077
T X M	S.E.d	0.099	0.107
	CD (0.05)	0.203	0.219

Table 8. Effect of nanoformulations on overall acceptability of "Bhendi hybrid COBh H4"

Days		3rd		5th		7th		9th	
Storage		Ambient	Cold	Ambient	Cold	Ambient	Cold	Ambient	Cold
Factors	Variables								
T	S.E.d	0.082	0.088	0.041	0.061	0.021	0.04	0.012	0.012
	CD (0.05)	0.168	0.180	0.083	0.124	0.043	0.082	0.025	0.024
M	S.E.d	0.041	0.044	0.020	0.03	0.011	0.02	0.006	0.006
	CD (0.05)	0.084	0.090	0.042	0.062	0.022	0.041	0.012	0.012
T X M	S.E.d	0.116	0.125	0.058	0.086	0.030	0.057	0.017	0.017
	CD (0.05)	0.237	0.255	0.118	0.175	0.061	0.116	0.035	0.034

4. CONCLUSION

Minimizing the post-harvest losses in okra with safe, effective and economic mean is the major challenge. Therefore, 2% Enhanced Freshness formulation using dip method in cold storage condition has turned out to be most effective and easy to use in above investigation in extending the shelf life of okra cv. Bhendi hybrid COBh H4.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Kodandaram MH, Kumar YB, Banerjee K, Hingmire S, Rai AB, Singh B. Field bioefficacy, phytotoxicity and residue dynamics of the insecticide flonicamid (50 WG) in okra [*Abelmoschus esculenta* (L) Moench]. Crop Protection. 2017;94:13-19.
2. Singh RK, Singh RR, Pandey RC. Screening of okra, *Abelmoschus esculentus* varieties/ cultivars against root-knot nematode, Meloidogyne incognita. Current Nematology. 1993;4(2): 229-232.
3. Gundewadi G, Rudra SG, Sarkar DJ, Singh D. Nanoemulsion based alginate organic coating for shelf life extension of okra. Food Packaging and Shelf Life. 2018;18:1-12.
4. Saberi B, Golding JB, Marques JR, Pristijono P, Chockchaisawasdee S, Scarlett CJ, Stathopoulos CE. Application of biocomposite edible coatings based on pea starch and guar gum on quality, storability and shelf life of 'Valencia' oranges. Postharvest Biology and Technology. 2018;137:9-20.
5. Premalakshmi V, Subramanian KS, Sankar MMC. Effect of postharvest treatments and storage conditions on shelf life and vegetable quality of Brinjal; 2022.
6. Nasrin TAA, Molla MM, Hossaen MA, Alam MS, Yasmin L. Effect of postharvest treatments on shelf life and quality of tomato. Bangladesh Journal of Agricultural Research. 2008;33(4):579-585.
7. Paliyath G, Subramanian J. Phospholipase D inhibition technology for enhancing shelf life and quality. Postharvest Biology and Technology of Fruits, Vegetables, and Flowers. 2008;1:240-245.
8. Baldwin EA, Burns JK, Kazokas W, Brecht JK, Hagenmaier RD, Bender RJ, Pesis EDNA. Effect of two edible coatings with different permeability characteristics on mango (*Mangifera indica* L.) ripening during storage. Postharvest Biology and Technology. 1999;17(3):215-226.
9. Mannozzi C, Cecchini JP, Tylewicz U, Siroli L, Patrignani F, Lanciotti R, Romani S. Study on the efficacy of edible coatings on quality of blueberry fruits during shelf-life. LWT-Food Science and Technology. 2017;85:440-444.
10. Nawab A, Alam F, Hasnain A. Mango kernel starch as a novel edible coating for enhancing shelf-life of tomato (*Solanum lycopersicum*) fruit. International Journal of Biological Macromolecules. 2017;103:581-586.
11. López Camelo AF, Gómez PA. Comparison of color indexes for tomato ripening. Horticultura Brasileira. 2004;22: 534-537.
12. Tiwari K, Paliyath G. Microarray analysis of ripening-regulated gene expression and its modulation by 1-MCP and hexanal. Plant Physiology and Biochemistry. 2011;49(3): 329-340.
13. Sulaimankhil Z, Sethi S, Sharma RR, Verma MK, Dahuja A, Bhowmik A. Influence of aqueous hexanal on quality of 'Royal Delicious' apple during cold storage. Acta Physiologiae Plantarum. 2021;43:1-10.
14. El-Mogy MM, Ali MR, Darwish OS, Rogers HJ. Impact of salicylic acid, abscisic acid, and methyl jasmonate on postharvest quality and bioactive compounds of cultivated strawberry fruit. Journal of Berry Research. 2019;9(2):333-348.
15. Cheema A, Padmanabhan P, Subramanian J, Blom T, Paliyath G. Improving quality of greenhouse tomato (*Solanum lycopersicum* L.) by pre-and postharvest applications of hexanal-containing formulations. Postharvest Biology and Technology. 2014;95:13-19.
16. Venkatachalam K, Muthuvel I, Sundaresan S, Subramanian KS, Janaki JG, Sullivan JA, Subramanian J. Post-harvest dip of

enhanced freshness formulation to extend the shelf life of banana (*Musa acuminata* cv. Grand Naine) in India. Tropical Agriculture; 2018.
17. Hutchinson MJ, Ouko JR, Ambuko J, Owino WO, Subramanian J. Effects of hexanal dip on the post-harvest shelf life and quality of papaya (*Carica papaya* L.) fruit. Tropical Agriculture; 2018.
18. Horwitz W. Official methods of analysis. Washington, DC: Association of Official Analytical Chemists. 1975;222.
19. Ray A, Ghosh S, Kanjilal A, Mukherjee A, Datta S. Antimicrobial properties of chitosan nanoparticles and their role in post-harvest shelf life extension. Journal of Environmental Science, Toxicology and Food Technology. 2022;16(6):51-60.
20. Falade KO, Omojola BS. Effect of processing methods on physical, chemical, rheological, and sensory properties of okra (*Abelmoschus esculentus*). Food and Bioprocess Technology. 2010;3:387-394.
21. Arise AK, Arise RO, Akintola AA, Idowu OA, Aworh OC. Microbial, Nutritional and Sensory Evaluation of Traditional Sundried Okra (Orunla) in Selected Markets in South-Western Nigeria; 2012.

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