Quality Assurance and Safety of Crops & Foods, 2025; 17(1): 100–111

Postharvest quality response of green chili (*Capsicum Frutescens* L.) fruits to different concentrations of salicylic acid and calcium chloride

Zoya Tariq[1,2], Nadia Riaz[1,3], Irfan Anjum[4], Zubaida Yousaf[1*], Arusa Aftab[1], Zainab Maqbool[1], Kishwar Sultana[5], Riaz Ullah[6], Zafar Iqbal[7]

[1]*Department of Botany, Lahore College for Women University, Lahore, Pakistan;* [2]*Toronto Botanical Gardens, 777 Lawrence Avenue East, Toronto, ON, M3C 1P2;* [3]*Faculty of Science and Engineering, Linköping University, Sweden;* [4]*Department of Basic Medical Sciences, Shifa College of Pharmaceutical Sciences, Shifa Tameer-e-Millat University, Islamabad, Pakistan;* [5]*Department of Pharmacy and Allied Health Sciences, Iqra University, H-9 Campus, Islamabad;* [6]*Department of Pharmacognosy, College of Pharmacy, King Saud University, Riyadh, Saudi Arabia;* [7]*Department of Surgery, College of Medicine, King Saud University, P.O. Box 7805, Riyadh, 11472, Kingdom of Saudi Arabia*

***Corresponding Author:** Zubaida Yousaf, Department of Botany, Lahore College for Women University, Lahore, Pakistan. Email: zubaida.yousaf@lcwu.edu.pk

Academic Editor: Charles Okpala, PhD., UGA Cooperative Extension, College of Agricultural and Environmental Sciences, University of Georgia, Athens, GA 30602, USA

Received: 24 June 2024; Accepted: 9 November 2024; Published: 27 January 2025

RESEARCH ARTICLE

Abstract

Capsicum frutescens L. (green chili) is an important food crop normally used in traditional cuisine. It is soft in texture with high moisture content and active metabolism; hence, it is highly vulnerable to quality deterioration. The object of this study was to explore the storage conditions for the enhancement of postharvest storage life of *C. frutescens* with six treatments: 1mM/L (T1), salicylic acid (SA) 2mM/L (T2), SA 4mM/L (T3), calcium chloride ($CaCl_2$) 0.5% (T4), $CaCl_2$ 1.5% (T5), and $CaCl_2$ 2% (T6). Treated fruits were packed in three different types of packing materials (polythene, paper, and cardboard), and the experiment was duplicated to store at 10°C and 25°C. The quality of fruits was assessed by decay percentage, weight loss percentage, length of shelf life, and antioxidant activities. The given treatments improved the quality of chili. The shelf life was significantly enhanced by 4mM/L SA and 2% $CaCl_2$ treatment for up to 56 days in cardboard packaging at 10°C.

Keywords: Calcium chloride; green chili; postharvest; salicylic acid; shelf life

Introduction

Capsicum frutescens L., commonly known as green chili, is an annual herbaceous member of the family Solanaceae. It is grown as cash crop, especially in tropical and subtropical regions of the world (Panigrahi *et al.*, 2017). Capsicum is widely used for its aroma and taste in culinary applications (Mi *et al.*, 2023). China, Mexico, Indonesia, Jordan, and Egypt accounted for 50.8%, 7.4%, 5.5%, 4.5%, and 2.1% of global chili production, respectively (Crippa *et al.*, 2022). Capsicum is extensively grown in Pakistan covering an area of 38.4 hectares producing 90,400 tons, with the major chili producing areas being Sindh, Punjab, and some parts of Baluchistan. It is exported in various forms like fresh green chili, dried chili powder, and as oleoresin to various countries, including to the Gulf States, the United States, Canada, Sri Lanka, the United Kingdom, Singapore, and Germany,

ISSN 1757-837X online, DOI 10.15586/qas.v17i1.1524

contributing 1.5% to the gross domestic product (GDP) growth of Pakistan. The yield of chili showed great fluctuation over the years (Enamullah *et al.*, 2022). Recently, different mechanical techniques are being applied to dry chili for export, but the required results could not be obtained. In Europe, the major producers of chili are Spain, Macedonia, Hungary, Serbia, and Croatia (Duan *et al.*, 2022). Phenotypically, chili is oblong, 1.5–2.5 cm long, and lanceolate in shape (Vinkovic *et al.*, 2018), and used in food for color and flavor. It also has many nutritional and medicinal benefits. Capsaicinoids is the most common phytochemical group synthesized and accumulated in placental tissues of the chili fruit, contributing toward the pungent taste. The quality of chili depends on the concentration of capsinoides, with the major chemical constituents being (i) capsaicin, (ii) dihydro capsaicin, and (iii) non-dihydrocapsaicin, collectively termed as capsaicinoids (Pola *et al.*, 2018; Topuz and Ozdemir, 2020). Fresh green chilies contain a valuable amount of vitamin A and C (major antioxidants), in addition to neutral and acidic phenols. Antioxidants play an important role in the maintenance of health and prevention of heart diseases, cancer, delaying aging, and in neurodegenerative diseases, deriving significant attention of scientists to improve the health of consumers (Koo *et al.*, 2020; Hanif *et al.*, 2020). Capsaicinoids are economically very viable because of their use in the food, cosmetic, military, and pharmaceutical industry (Zhi *et al.*, 2017; Gruber *et al.*, 2022). Maintenance of functional phytochemicals in fruit from field to consumer is a big challenge. Temperature and moisture are two important factors that contribute toward the quality and shelf life of green chili. To maintain quality and prolong postharvest storage duration (shelf life), it is essential to store them at their peak—freshness, taste, and color—for a desired time period. The conventional methods to store and preserve chili include refrigeration, drying, and salting, with refrigeration being essential to store fruits for a comparatively long time (Birgen *et al.*, 2020). However, salting and drying do not preserve chili in their original shape, taste, freshness, and odor. Today, scientists are researching ways to improve the shelf life of vegetables and fruits for an extended time. Methods like irradiation with different gamma rays frequencies have been tested on vegetables to prolong shelf life. However, this technology is expensive and may affect the important constituents of food like vitamin C. The quality maintenance of vegetable or fruit after irradiation is still a big question mark (Jourki and Khazaei, 2014); however, the use of phytohormones and chemicals like calcium chloride ($CaCl_2$) may be beneficial in achieving the goal.

Salicylic acid (SA) is a phytohormone that plays an important role in the physiological processes (seed germination, flowering, fruit ripening, etc.) and plant defense systems against stress (biotic and abiotic) (Koo *et al.*, 2020). SA belongs to phenolic compounds and is emerging as a natural compound that can maintain the quality of fruits and vegetables during storage. Literature confirms that postharvest application of SA enhanced the shelf life of papaya used for the reduction of weight loss (WL), senescence, decay loss, firmness, moisture content, and increasing antioxidant activities (Hanif *et al.*, 2020). $CaCl_2$ is a mineral used to cure calcium deficiency in a human body and a good source of calcium ion that plays multiple roles in the plant physiological processes. Application of calcium on fruit maintains the integrity of the cell wall and delays the senescence (Zhi *et al.*, 2017). Along with phytohormones and minerals, appropriate packaging also plays a crucial role in enhancing the shelf life by protecting the product from physical, chemical, and biological hazards. Therefore, this study was planned to evaluate the efficacy of SA and $CaCl_2$ application on *C. frutescens* fruits stored in three different packaging materials at two different temperatures for shelf life enhancement.

Materials and Methods

This study was carried out to explore the most effective phytohormones or mineral concentration, packaging material, and temperature to prolong the shelf life of *C. frutescens* for longer preservation of the antioxidant constituents and other useful components to compliment efficient utilization.

Plant material and processing

Freshly harvested green chili (20 days) was transported to the research laboratory from a farm in Lahore. Special care was taken to select the fruit where the criteria for selection were uniform shape/size with no blemishes and defects. To remove any infection, fruit was dipped in 2% sodium hypochlorite for 2 minutes, rinsed with water, and then dried. Total plant material used in the experiment was 40 kg which was divided into two groups (one for SA treatment and the other for $CaCl_2$ treatment), comprising of 20 kg plant material for each group.

Experiment design was the completely randomized split block with six treatments: SA 1mM/L (T1), SA 2mM/L (T2), SA 4mM/L (T3), $CaCl_2$ 0.5% (T4), $CaCl_2$ 1.5% (T5), $CaCl_2$ 2% (T6), and control. The postharvest treatments comprising of SA and $CaCl_2$ of different concentrations were given by dipping the fruit in respective concentration for 15 mins and then air dried for 30 mins. Chili was then packed in three different types of packing materials—polythene bags, paper bags, and cardboard—and stored in two different storage conditions—one group with 10°C and other 25°C. Each treatment was in triplicate.

Weight loss

WL was recorded every 8 days by following standard method of Association of Official Agricultural Chemists (AOAC) (16). Moisture content was calculated by using the following formula (Sinha *et al.*, 2019):

$$\text{Moisture Content} = \frac{(\text{IW} - \text{FW})}{\text{IW}} \times 100$$

where IW = initial weight and FW = final weight (g).

Decay percentage

The decay percentage of all the fruits was calculated by the method given by Solanki *et al.* (2022). The percentage of decay loss was calculated by using the following formula:

$$\text{Decay Ioss \%} = \frac{\text{nr}}{\text{n0}} \times 100$$

where nr = the number of decayed grapes and $n0$ = the number of total grapes.

Length of shelf life

The length of shelf life was calculated by counting the days required to attain the final stage in which fruit remains marketable (Devi *et al.*, 2022).

Enzyme extraction

Peroxidase (POD) enzyme was extracted from pulp tissue and 10% of the w/v (weight of solute dissolved in volume of the solvent) pulp homogenate was made by homogenizing the pulp tissue of the fruit with solution (20mM tris-HCl [hydrochloric acid], 20mM Cysteine HCl, 20mM EDTA (ethylenediaminetetraacetic acid), and 0.05% Triton-X-^{1}00). This homogenate was centrifuged at 15,000×g for 30 minutes in refrigerated centrifuge at 4°C (Phornvillary *et al.*, 2019).

Assay for peroxidase

POD activity was determined by the method described by Kamińska *et al.* (2020). The reaction mixture contained 0.025 mL of extract enzyme, 0.975 mL of phosphate buffer (pH 5.5, 0.05M), 1 mL guaiacol solution, and 1mL of H_2O_2. Wavelength absorbance was calculated at 470 nm.

Antioxidant activity

DPPH (2,2-Diphenyl-1-picrylhydrazyl) is used to evaluate the free radical scavenging activity of a fruit extract by preparing a methanol extract of the fruit. this activity was performed by following methodology of Theofanous *et al.* (2022). The reaction mixture was prepared by mixing 0.2 mL of the plant extract and 1.4 mL of DPPH solution (prepared in methanol) and incubated for 30 minutes in the dark. Absorbance was recorded at 517 nm by spectrophotometer.

Total antioxidant activity

The total antioxidant capacity of methanol extract of chili was evaluated by following the protocol set by Zewdie *et al.* (2022). Reagent solution (3 mL) consisting of 0.6M sulfuric acid, 28mM sodium phosphate, and 4mM/L ammonium molybdate was prepared. The reaction mixture contained 0.3 mL fruit extract and 3 mL reagent solution. This mixture was incubated for 60 minutes at 95°C. Wavelength absorbance was recorded at 695 nm.

Statistical analysis

The experimental design for the study was the completely randomized split block with six treatments. Each treatment along with control was run in triplicate. The data was presented as mean ± standard deviation. Mean separation was done by using the least significant difference (LSD) with $p < 0.05$ level and the statistical analysis was done using IBM SPSS statistics 20 software (Carvalho *et al.*, 2023).

Results and Discussion

Weight loss and decay percentage

The degrees of WL and decay percentage are important indicators for the shelf life of fruits and vegetables. In this study, WL and decay percentage directly related to temperature was observed. Fruits stored at 10°C had a low degree of decay percentage and WL as compared to the fruits stored at 25°C (Tables 1 and 2). The reason for the high decay percentage and WL at 25°C was because high temperature increases the respiration rate and the rate of metabolic processes. This increased rate leads toward the efficiency of substrates like sugars

Table 1. Effect of postharvest treatments and storage temperatures on weight loss percentage of the capsicum fruit during storage conditions.

	10°C							25°C	
Days	**8**	**16**	**24**	**32**	**40**	**48**	**56**	**8**	**16**
Cardboard Packaging									
T1	1.4 ± 0.57^{a}	2.4 ± 0.57^{a}	4.4 ± 1.15^{a}	6.7 ± 1.52^{ab}	9.7 ± 1.52^{a}	12.4 ± 1.52^{a}	–	2.4 ± 0.57^{a}	6.7 ± 1.52^{ab}
T2	1.4 ± 0.57^{a}	04 ± 10^{a}	6.4 ± 1.52^{ab}	8.7 ± 1.52^{bc}	11.7 ± 0.57^{b}	11.4 ± 4.61^{a}	–	4 ± 1^{a}	8.7 ± 1.52^{bc}
T3	0	0	0.4 ± 1.52^{ab}	1.7 ± 1.52^{ab}	2.4 ± 1.15^{a}	3.4 ± 0^{a}	11 ± 0^{a}	3 ± 1^{a}	6.7 ± 1.52^{ab}
T4	2 ± 1^{a}	3 ± 1^{a}	5 ± 1^{abc}	7 ± 1^{abc}	9.7 ± 1.52^{a}	11 ± 0.57^{a}	–	3 ± 1^{a}	7 ± 1^{abc}
T5	2 ± 1^{a}	3 ± 1^{a}	5 ± 1^{abc}	7 ± 1^{abc}	9.7 ± 1.52^{a}	11 ± 0.57^{a}	–	3 ± 1^{a}	7 ± 1^{abc}
T6	0	1.4 ± 0.57^{a}	2.4 ± 0.57^{a}	4.4 ± 0.57^{a}	6.4 ± 0.57^{a}	9.4 ± 1.15^{a}	11.7 ± 0.57^{a}	2.4 ± 0.57^{a}	6.4 ± 0.57^{a}
T7	1.4 ± 0.57^{a}	4 ± 1	7 ± 1.732^{bcd}	9 ± 1^{c}	8.7 ± 0.57^{a}	9.7 ± 1.527^{a}		4 ± 1^{a}	9 ± 1^{c}
Polythene Packaging									
T1	3.4 ± 0.57^{ab}	6.7 ± 3.05^{abc}	9 ± 2^{a}	13.4 ± 0.57^{a}	16.4 ± 1.15^{ab}	21 ± 1^{ab}	–	6.7 ± 3.05^{a}	13.4 ± 0.57^{ab}
T2	2.7 ± 2.081^{a}	6.7 ± 0.57^{abc}	10 ± 1.7^{a}	14.4 ± 2.3^{ab}	19.4 ± 1.52^{ab}	21.4 ± 2.08^{ab}	–	6.7 ± 0.57^{a}	14.4 ± 2.30^{ab}
T3	0	0	0.4 ± 1.52^{ab}	1.7 ± 1.52^{ab}	2.4 ± 1.15^{a}	3.4 ± 0^{a}	–	6 ± 1^{a}	14 ± 1ab
T4	4 ± 1^{abc}	5 ± 1^{a}	9 ± 1^{a}	12 ± 1^{a}	17 ± 1^{b}	19.4 ± 0.57^{a}	–	5 ± 1^{a}	12 ± 1^{a}
T5	4.4 ± 1.154^{abc}	9.4 ± 1.15^{cd}	12.7 ± 1.5^{a}	15.7 ± 1.52^{c}	17 ± 1^{ab}	22 ± 2^{b}	–	9.4 ± 1.15^{a}	15.7 ± 1.52^{b}
T6	4 ± 1^{abc}	8.4 ± 1.52^{bcd}	9 ± 1^{a}	13.4 ± 1.52^{a}	19 ± 1^{b}	23.4 ± 1.15^{bc}	–	8.4 ± 1.52^{a}	13.4 ± 1.52^{ab}
T7	6 ± 1^{c}	10.4 ± 1.52^{d}	11 ± 1^{a}	15.4 ± 1.52^{abc}	17 ± 1^{b}	25.4 ± 1.15^{d}	–	10.4 ± 1.52^{a}	15.4 ± 1.52^{b}
Paper Packaging									
T1	1.4 ± 0.57^{a}	3.7 ± 0.57^{a}	5.4 ± 1^{a}	9.4 ± 0.57^{a}	1.4 ± 0.57^{a}	1.4 ± 0.57^{a}	–	13.7 ± 0.5^{a}	16.7 ± 0.57^{ab}
T2	1.4 ± 0.5^{a}	3.7 ± 0.57^{a}	7 ± 1.15^{a}	9.4 ± 1.73^{abc}	2.7 ± 0.57a	3.4 ± 0.57^{a}	–	13.7 ± 2.08^{a}	17.7 ± 2.08^{b}
T3	1.4 ± 0.57^{a}	2.7 ± 0.5^{a}	4.7±0.5^{bcd}	9 ± 0.5^{a}	6 ± 1^{abc}	6 ± 1^{abc}	–	14.7 ± 1^{a}	18.7 ± 1.5^{bc}
T4	1.4 ± 0.57^{a}	2.4 ± 0.5^{a}	4.7 ± 0.5^{a}	8.4 ± 1^{ab}	1.4 ± 0.57^{a}	1.4 ± 0.57^{a}	–	12.7 ± 0.57^{a}	16 ± 0.5^{a}
T5	1.4 ± 0.5^{a}	3.7 ± 0.5^{a}	6 ± 0.5^{a}	9.4 ± 1^{a}	2.7 ± 0.57^{a}	3.4 ± 0.57^{a}	–	13.4 ± 1^{a}	17.7 ± 1.5^{b}
T6	1.4 ± 0.57^{a}	3 ± 0.5^{a}	6 ± 1^{abc}	11 ± 1.5^{bc}	6 ± 1^{abc}	6 ± 1^{abc}	–	13.7 ± 0.57^{ab}	18.4 ± 0.5^{b}
T7	1.4 ± 0.5^{a}	4 ± 0.5^{abc}	7.4 ± 1^{d}	12.7 ± 0.5^{d}	9 ± 1^{ab}	10 ± 1^{abc}	–	16.7 ± 1^{c}	22.7 ± 0.57^{d}

T1 (1mM/L), T2 (2mM/L), T3 (4mM/L), T4 (0.5% $CaCl_2$), T5 (1.5% $CaCl_2$), T6 (2% $CaCl_2$), and T7 control.

Table 2. Decay loss percentage of capsicum fruits during storage.

	10°C							25°C	
Days	**8**	**16**	**24**	**32**	**40**	**48**	**56**	**8**	**16**
Cardboard Packaging									
T1	0.55 ± 0.08^{c}	1.55 ± 0.08^{bc}	2.66 ± 0.1^{bc}	4.40 ± 0.1^{b}	6.60 ± 0.1^{b}	7.80 ± 0.2^{cd}	–	1.55 ± 0.086^{bc}	4.4 ± 0.173^{b}
T2	0.52 ± 0.12^{c}	1.63 ± 0.12^{abc}	2.76 ± 0.2^{bc}	4.23 ± 0.2^{b}	6.46 ± 0.4^{b}	7.80 ± 0.6^{cd}	–	1.63 ± 0.125^{abc}	4.23 ± 0.251^{b}
T3	0	0.866 ± 0.11^{c}	1.496 ± 0.09^{c}	2.33 ± 0.3^{c}	3.96 ± 0.05^{b}	6.41 ± 0.3^{b}	7.5 ± 0.5^{d}	1.49 ± 0.095^{c}	3.96 ± 0.057^{b}
T4	0.45 ± 0.005^{c}	1.33 ± 0.12^{c}	2.48 ± 0.02^{bc}	4.23 ± 0.02^{b}	6.61 ± 0.2^{b}	7.56 ± 0.1^{d}	–	1.33 ± 0.125^{cd}	4.23 ± 0.028^{b}
T5	0.76 ± 0.196^{ab}	1.36 ± 0.332^{cd}	2.73 ± 0.2^{bc}	4.20 ± 0.2^{b}	6.46 ± 0.1^{b}	8.53 ± 0.3^{c}	–	1.36 ± 0.332^{cd}	4.2 ± 0.2^{b}
T6	0	0.61 ± 0.104^{bc}	1.10 ± 0.173^{cd}	2.80 ± 0.05^{b}	4.28 ± 0.07^{b}	6.16 ± 0.2^{b}	8.56 ± 0.4^{c}	1.1 ± 0.173^{b}	4.28 ± 0.579^{b}
T7	0.76 ± 0.070^{ab}	1.85 ± 0.100^{d}	3.55 ± 0.08^{a}	5.93 ± 0.07^{a}	8.08 ± 0.1^{b}	10.91 ± 0.08^{a}	–	$1.85 \pm 0.1^{a,b}$	5.93 ± 0.076^{a}
Polythene Packaging									
T1	0.76 ± 0.05^{bc}	1.95 ± 0.08^{b}	3.33 ± 0.28^{b}	4.96 ± 0.02^{b}	7.41 ± 0.3^{ab}	8.78 ± 0.25^{cde}	–	1.95 ± 0.086^{bc}	4.96 ± 0.028^{a}
T2	0.8 ± 0.1^{bc}	1.93 ± 0.07^{b}	3.38 ± 0.1^{b}	4.95 ± 0.08^{b}	6.9 ± 0.08^{b}	8.16 ± 0.28^{e}	–	1.93 ± 0.076^{bc}	4.95 ± 0.086^{a}
T3	0.73 ± 0.02^{bc}	1.53 ± 0.05^{c}	2.45 ± 0.42^{c}	4.86 ± 0.05^{b}	6.95 ± 0.08^{b}	9.41 ± 0.38^{c}		1.53 ± 0.057^{bc}	4.86 ± 0.057^{a}
T4	0.56 ± 0.1^{c}	1.7 ± 0.7^{bc}	2.46 ± 0.02^{c}	4.63 ± 0.23^{b}	6.95 ± 0.57^{b}	8.43 ± 0.4^{de}	–	1.7 ± 0.3^{c}	4.63 ± 0.230^{a}
T5	0.93 ± 0.057^{ab}	1.86 ± 0.12^{bc}	2.56 ± 0.49^{c}	4.95 ± 0.08^{b}	6.95 ± 0.57^{b}	9.25 ± 0.4^{cd}	–	1.86 ± 0.125^{bc}	4.95 ± 0.086^{a}
T6	0.86 ± 0.023^{bc}	1.63 ± 0.22^{bc}	2.53 ± 0.46^{c}	5.08 ± 0.23^{b}	6.86 ± 0.02^{b}	8.91 ± 0.07^{cde}	–	1.63 ± 0.225^{bc}	5.08 ± 0.236^{a}
T7	1.18 ± 0.175^{a}	2.78 ± 0.25^{a}	4.33 ± 0.15^{a}	6.95 ± 0.08^{a}	9.63 ± 0.37^{a}	12.78 ± 0.25^{a}	–	2.78 ± 0.252^{a}	6.95 ± 0.086^{a}
Paper Packaging									
T1	0.68 ± 0.02^{bc}	1.88 ± 0.05^{ab}	2.93 ± 0.07^{c}	4.66 ± 0.02^{bc}	6.93 ± 0.07^{c}	8.23 ± 0.2^{ef}	–	1.88 ± 0.057^{ab}	4.66 ± 0.028^{bc}
T2	0.73 ± 0.05^{ab}	1.83 ± 0.03^{b}	3.11 ± 0.2^{bc}	4.86 ± 0.1^{bc}	6.88 ± 0.05^{c}	8.45 ± 0.42^{de}	–	1.83 ± 0.028^{b}	4.86 ± 0.125^{bc}
T3	0.7 ± 1.3^{cd}	1.41 ± 0.05^{d}	2.23 ± 0.2^{d}	4.13 ± 0.1^{c}	6.9 ± 0.08^{c}	8.85 ± 0.5^{c}	–	1.41 ± 0.057^{d}	4.13 ± 0.115^{d}
T4	0.48 ± 0.02^{d}	1.38 ± 0.03^{d}	2.38 ± 0.05^{d}	4.25 ± 0.2^{c}	6.51 ± 0.2^{c}	7.76 ± 0.11^{f}	–	1.38 ± 0.028^{d}	4.25 ± 0.25^{cd}
T5	0.68 ± 0.02^{bc}	1.68 ± 0.02^{c}	2.86 ± 0.02^{c}	4.9 ± 0.1^{bc}	6.98 ± 0.03^{c}	8.9 ± 0.08^{cd}	–	1.68 ± 0.026^{c}	4.9 ± 0.132^{b}
T6	0.68 ± 0.02^{bc}	1.36 ± 0.02^{d}	2.86 ± 0.1^{c}	4.61 ± 0.6^{bc}	6.73 ± 0.2^{c}	9.03 ± 0.15^{cd}	–	1.36 ± 0.028^{d}	4.61 ± 0.682^{bcd}
T7	0.78 ± 0.07^{ab}	1.93 ± 0.07^{a}	3.88 ± 0.1^{ab}	6.11 ± 0.202^{a}	8.33 ± 0.28^{a}	11.2 ± 0.18^{a}	–	1.93 ± 0.076^{ab}	6.11 ± 0.202^{a}

T1 (1mM/L), T2 (2mM/L), T3 (4mM/L), T4 (0.5% $CaCl_2$), T5 (1.5% $CaCl_2$), T6 (2% $CaCl_2$), and T7 control.

and proteins, with the ultimate result being WL (Zewdie *et al.*, 2022). Transpiration and its rate increase with an increase in temperature (Bovi *et al.*, 2016). First observation for the WL and decay percentage was made after 8 days in storage. The result with the three types of packing and two chemical treatments was: SA (1mM/L, 2mM/L, and 4mM/L) and $CaCl_2$ (0.5%, 1.5% and 2%). WL and decay percentage were higher in polythene packaging at both storage temperatures. Chili stored at 10°C treated with SA and $CaCl_2$ in cardboard packaging showed less degree of decay and WL as compared to paper and polythene packaging. As fruits and vegetables are vulnerable to moisture damage, they need to be stored in such packing materials which serve as a high humidity barrier but which do not desiccate the packed food stuff. Polythene serves as desiccator for fruits and vegetables because it keeps food stuff airtight; although paper packaging does not provide desiccation, it did act as a high humidity barrier. Cardboard packaging was proven to be the most suitable material for packing fruits. Chili treated with SA 4mM and $CaCl_2$ 2% showed less WL and decay as compared to the other treatments. Chili at 25°C lasted only for two weeks. As an electron donor, SA prevented normal respiration by producing free radicals. SA could reduce respiration rate and consequently decrease WL by closing stomata. Widyastuti and Gahayu (2022) observed that the application of $KMnO_4$ extended the shelf life of curly red pepper.

Length of shelf life

The maximum duration for which the fruit remained acceptable for market and consumption was 56 days. First observation regarding the morphological characters like freshness, color, and texture was recorded after 8 days of storage. The shelf life of chili as compared to the control fruits stored at 10°C extended significantly compared to those at 25°C (Figure 1). Shelf life of 56 days was attained in cardboard packaging, 49 days in paper, and 43 days in polythene by fruit treated with 2mM/L SA (T2) and $CaCl_2$ (T5). The obtained results indicated that the shelf life of chili significantly increased in all treated fruit stored at 10°C. The main cause of postharvest wilting, withering, and shortening of shelf life of fruit stored at 25°C was increased transpiration rate. The shelf life of curly red peppers was extended up to 21 days through the application of 0.10% concentration of $KMnO_4$ (Widyastuti and Gahayu, 2022).

Peroxidase activity

PODs are important iso enzymes involved in the capsaicin metabolism. These enzymes readily oxidize capsaicin, resulting in wilting and withering of fruit (Schweiggert *et al.*, 2006). At both storage conditions, POD increased with the storage duration. The fruit stored at 25°C showed

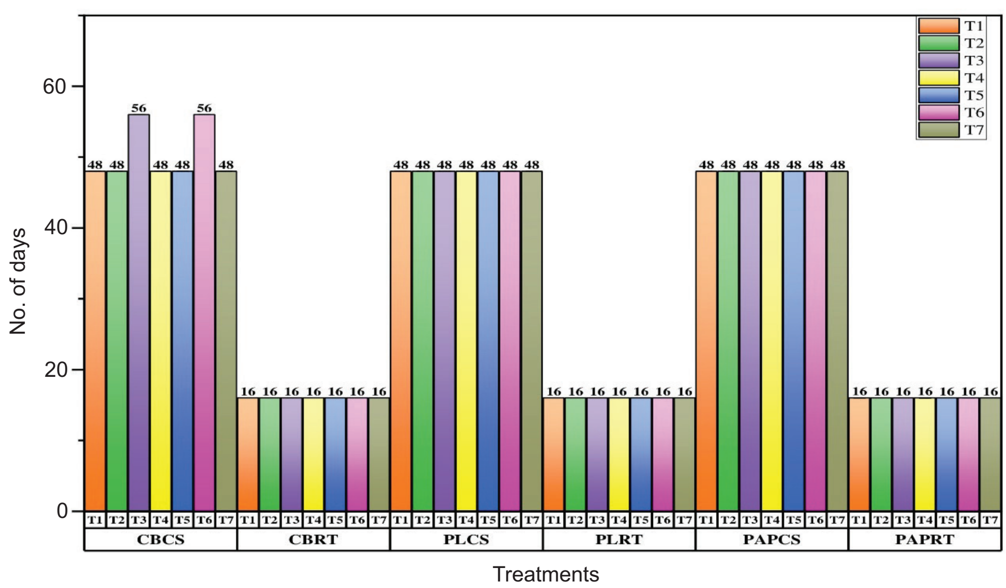

Figure 1. Shelf life of *Capsicum frutescence* fruits during storage. T1 (1mM/L/L SA), T2 (2mM/L SA), T3 (4mM/L Sa), T4 (0.5% $CaCl_2$), T5 (1.5% $CaCl_2$), T6 (2% $CaCl_2$), and T7 control, CBCS (cardboard cold storage 10°C), CBCS (cardboard room storage 25°C), PTCS (polythene bags 10°C), PTCS (polythene bags 25°C), PAPCS (paper packaging 10°C), and(PAPRT (paper packaging 25°C).

higher POD value as compared to those stored at 10°C (Figure 2). The results obtained in this study revealed that the application of SA and $CaCl_2$ increased the defense mechanism of the fruit. The POD value in cardboard packaging at 10°C T3 (SA 4mM/L) showed 0.202, which was higher than all the other SA treated fruit. POD activity of other treated fruit stored at 10°C T1 (SA 1mM/L) = 0.147 and T2 (SA 2mM/L) = 0.174. The POD values for $CaCl_2$ were T4 ($CaCl_2$ 0.5%) = 0.145, T5 ($CaCl_2$ 1.5%) = 0.172, and T6 ($CaCl_2$ 2%) = 0.200. The POD values for fruit stored at 10°C in polythene packaging were T1 (SA 1mM/L) = 0.136, T2 (SA 2mM/L) = 0.165, and maximum value was shown by T3 (SA 4mM/L) = 0.174, T4 ($CaCl_2$ 0.5%) = 0.134, T5 ($CaCl_2$ 1.5%) = 0.164, and T6 ($CaCl_2$ 2%) = 0.182. The maximum values were shown by T3 and T6. In paper packaging, the POD values for fruit stored at 10 °C were T1 (SA 1mM/L) = 0.138, T2 (SA 2mM/L) = 0.168, T3 (SA 4mM/L) = 0.193, T4 ($CaCl_2$ 0.5%) = 0.137, T5 ($CaCl_2$ 1.5%) = 0.166 and T6 ($CaCl_2$ 2%) = 0.200. Chili stored at 25°C among the three packaging materials showed maximum value in the second week; after the second week, chili peppers could not survive at 25°C. The maximum values for POD were shown by fruit treated with T3 and T6. The values for POD were T3 (SA 4mM/L) = 0.123 and T6 ($CaCl_2$ 2%) = 0.121 for cardboard packaging, T3 (SA 4mM/L) = 0.111 and T6 ($CaCl_2$ 2%) = 0.111 for polythene packaging, and T3 (SA 4mM/L) = 0.121 and T6 ($CaCl_2$ 2%) = 0.119 for paper packaging. Increase in POD activity with storage duration was also observed by Kantakhoo and Imahori (2021).

DPPH radical scavenging activity

Oxidative stress is the major contributing factor in the living system that leads toward the aging phenomenon (Kantakhoo and Imahori, 2021). Free radicals are produced as the result of oxidation. Plants like chili have chemical compounds that are antioxidant in nature and their activities can be increased through different treatments. During storage, the DPPH radical scavenging activity increased in both control and treated fruits stored at 25°C and 10°C (Figure 3). As compared to the control fruit, the activity was found to be higher in SA and $CaCl_2$ treated fruit, the reason being is that SA application acts as an antitranspirant agent and retains the moisture loss (Hanif *et al.*, 2020). Usage of $CaCl_2$ as postharvest treatment delayed the time of the fruit to reach its maturation stage by reducing the accumulation of sugars and organic acids. Consequently, radical scavenging activity was higher in T3 (SA 4mM/L) and T6 ($CaCl_2$ 2%) in all types of packing. Scavenging activity increased up to 40 days and then showed consistency, leading toward the decline of the activity at the end of the storage period. The application of SA and $CaCl_2$ reduces the oxidation of phytochemicals. In this study, α tocopherol and BHT (β-hydroxyltoluene) were used as a standard in the absorption of 517 nm to determine scavenging activity. Maximum DPPH radical scavenging activity (%) was observed by T3 (SA4mM/L), that is, 64.6%, and T6 ($CaCl_2$ 2%), that is, 63.4% d in cardboard packaging at 10°C on the 56th day. Kanwal *et al.* (2020) documented that okra pods survived for four days at 20°C and 20 days at 7°C through the combined treatment of 1-MCP (1-methylcyclopropene) and MAP (modified atmosphere packaging).

Total antioxidant activity

The total antioxidant capacity of chili was used to determine the changes in antioxidant activity at both the storage conditions at 10°C and 25°C (Figure 4); the antioxidant activity was higher in chili treated with SA and $CaCl_2$. Both chemicals have the ability to reduce transpiration rate and decrease the accumulation of organic acid and sugars, which can delay metabolic processes and consequently prolong shelf life. The antioxidant activity increased significantly for up to 40 days. The increased antioxidant activity indicates strength of defense mechanism of fruit to fight against oxidative stress. Two standards α-tocopherol and BHT were used to determine the total antioxidant activity at 695 nm. The maximum value of antioxidant activity was attained by T3 (SA 4mM/L) and T6 ($CaCl_2$ 2%) after 56 days in cardboard packaging at 10°C, which is 0.407 and 0.404, respectively. Chili stored at 25°C in all packaging showed maximum increase in the second week of storage: T3 (SA 4mM/L) 0.218 and T6 ($CaCl_2$ 2%) 0.205 for cardboard packaging, T3 (SA 4mM/L) 0.183 and T6 ($CaCl_2$ 2%) 0.197 for polythene packaging, and T3 (SA 4mM/L) 0.206 and T6 ($CaCl_2$ 2%) 0.204 for paper packaging. After the second week, chili could not survive at 25°C. In a study conducted on strawberry, it reported that application of *Lemon verbena* bio extract increases the total antioxidant activity of strawberry fruits during storage (Moshari-Nasirkandi *et al.*, 2020).

Conclusions

The shelf life of chili peppers significantly enhanced with postharvest application of SA (4mM/L) and $CaCl_2$ (2%) up to 56 days in cardboard packaging, up to 48 days by 4mM/L SA, and 2% $CaCl_2$ at 10°C in paper packaging. By these treatments and cardboard packaging, the fruit can be stored for longer duration with reduced spoilage.

Data Availability Statement

The data will be available from the corresponding author upon reasonable request.

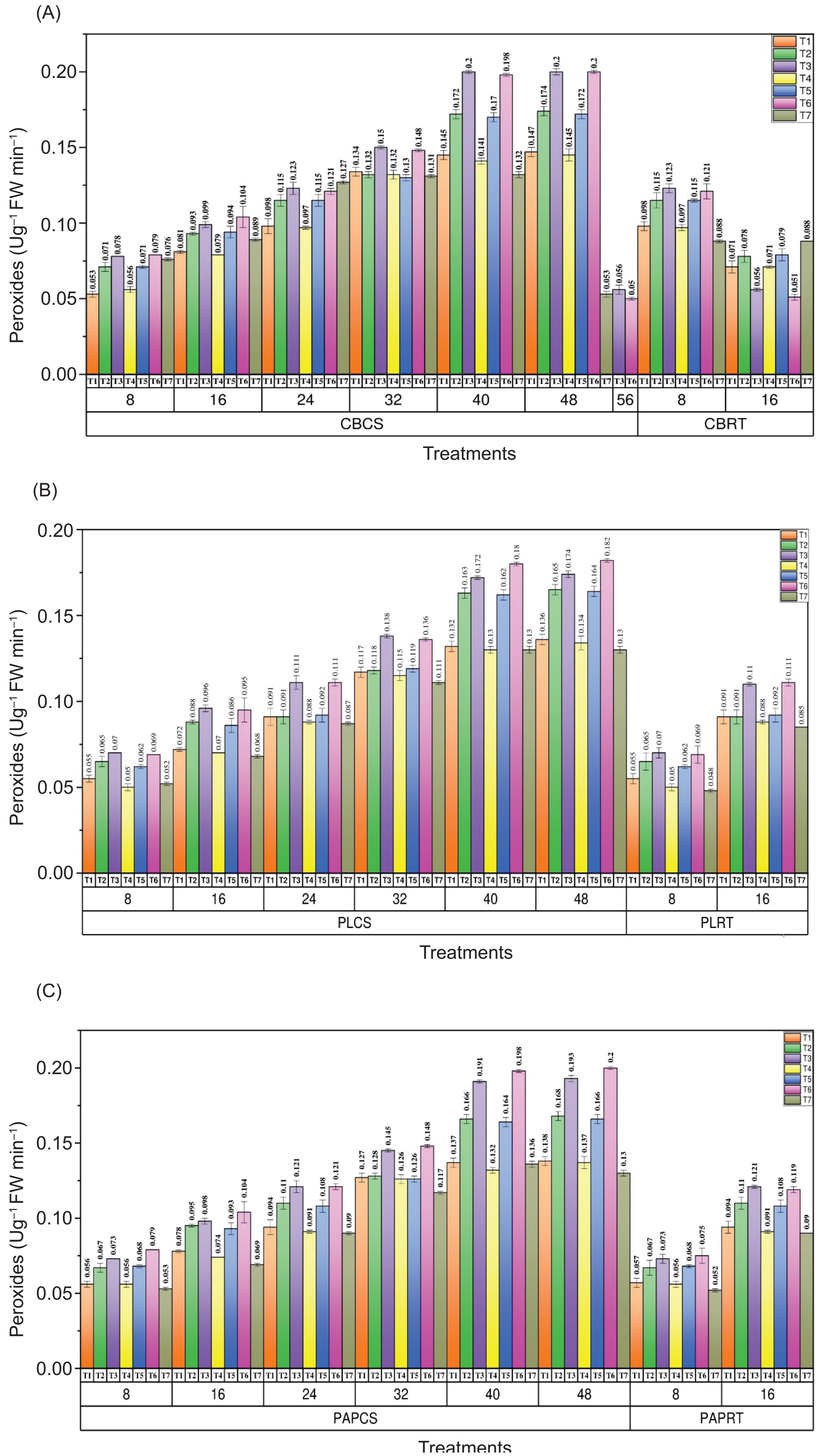

Figure 2. Peroxidase (POD) activity of capsicum fruit during storage in different conditions (A) Cardboard, (B) Polythene, and (C) Paper. The values are expressed in terms of U g^{-1} FW.

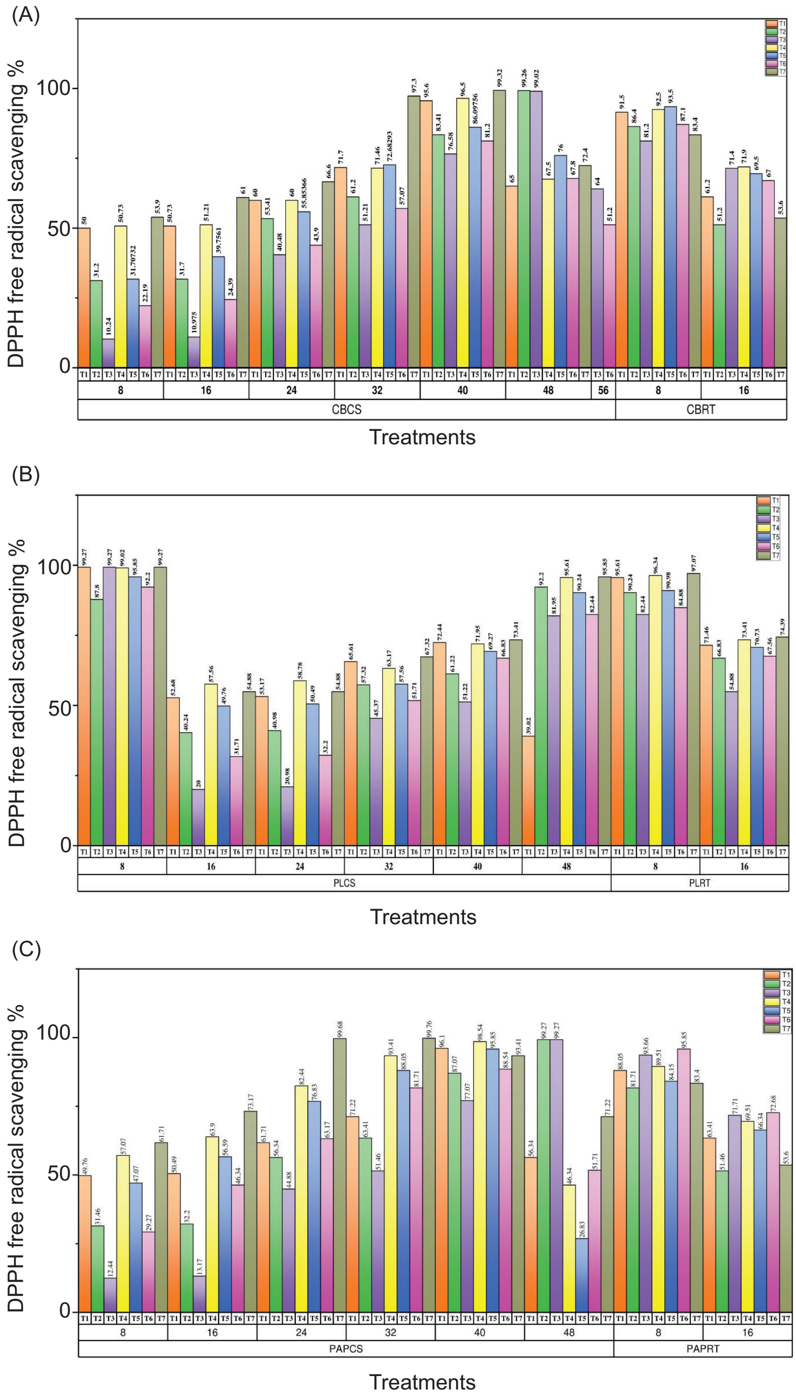

Figure 3. **Effect of postharvest treatments and storage temperatures on DPPH scavenging activity of the capsicum fruit during storage in different packaging materials (A) Cardboard, (B) Polythene, and (C) Paper. The values of standards taken are α-tocopherol A517 nm = 0.095 and BHT (β-hydroxytoulene) A517 nm = 0.190. Values from a to f represent higher to lower rank based on the level of significance.**

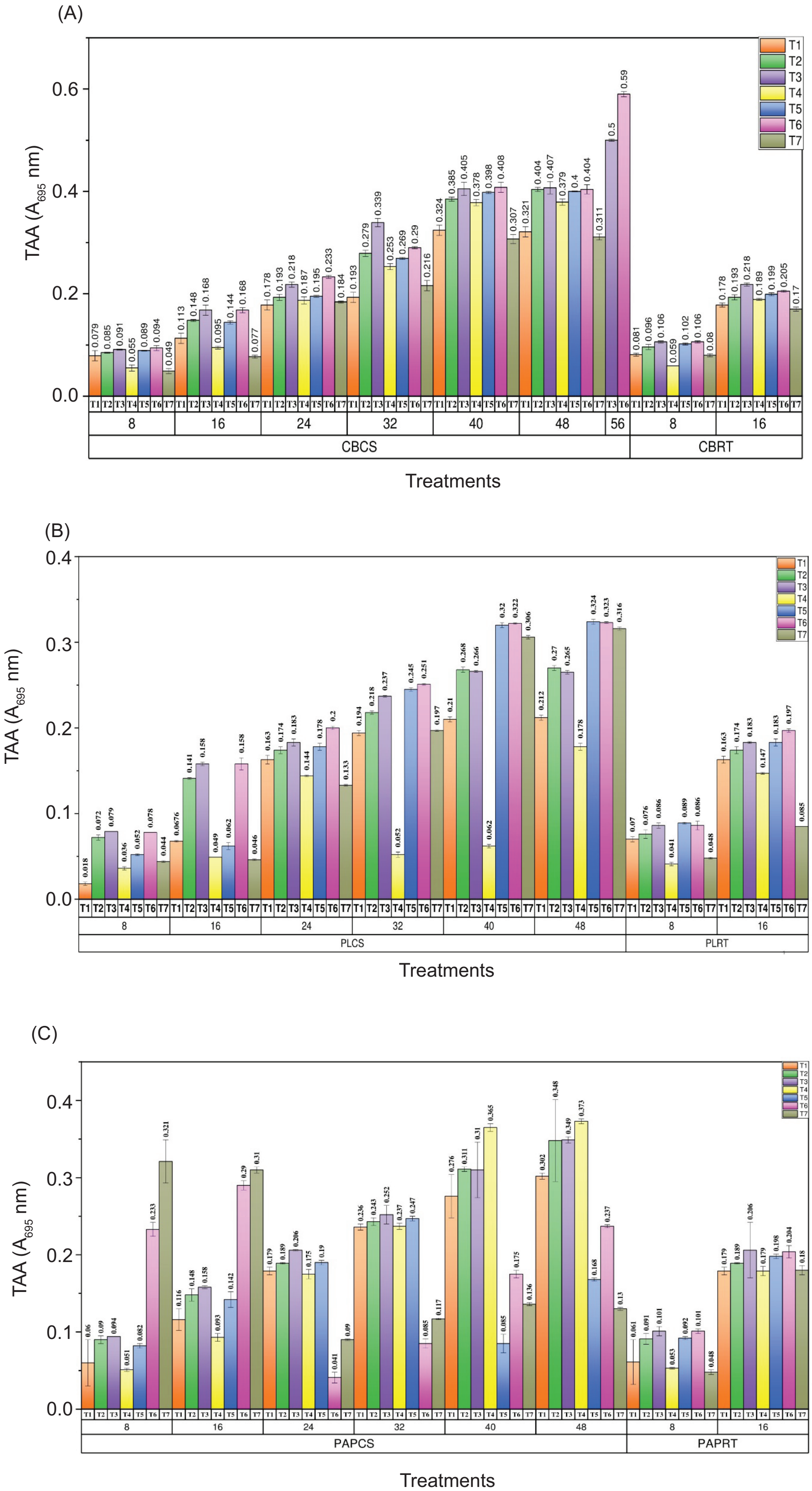

Figure 4. Effect of postharvest treatments and storage temperatures on total antioxidant activity of capsicum fruit during storage in different packaging materials (A) Cardboard, (B) Polythene, and (C) Paper. The value of standards taken are α-tocopherol A517 nm = 0.095.

Author Contributions

Z.T. and N.R. (Experimentation), Z.Y. (Supervision), R.U., Z.I., and I.A. (Data curation), A. A. (Analysis), and Z.M. (Write up). All authors have read the final version and approved its contents.

Conflicts of Interest

There is no potential conflict of interest among authors related to this manuscript.

Funding

The authors wish to thank Researchers Supporting Project number (RSP2025R110) at King Saud University, Riyadh, Saudi Arabia, for financial support.

References

Birgen BJ, Njue LG, Kaindi DM, Ogutu FO, Owade JO. Determinants of microbial contamination of street-vended chicken products sold in Nairobi County, Kenya. Int J Food Sci 2020;1–8. https://doi.org/10.1155/2020/2746492

Bovi G, Caleb O, Linke M, Rauh C, Mahajan P. Transpiration and moisture evolution in packaged fresh horticultural produce and the role of integrated mathematical models: A review. Biosyst Eng 2016;150:24–39. https://doi.org/10.1016/j.biosystemseng.2016.07.013

Carvalho A, Mendes F, Borges P, Kramer M. A brief review of the classic methods of experimental statistics. Acta Sci Agron 2023;45:e56882. https://doi.org/10.4025/actasciagron.v45i1.56882

Crippa M, Solazzo E, Guizzardi D, Tubiello F, Leip A. Climate goals require food systems emission inventories. Nat Food 2023;3(1):1.

Devi LS, Kalita S, Mukherjee A, Kumar S. Carnauba wax-based composite films and coatings: Recent advancement in prolonging postharvest shelf-life of fruits and vegetables. Trends Food Sci 2022;129:296–305. https://doi.org/10.1016/j.tifs.2022.09.019

Duan Y, Gao S, Hanson B. Effects of biochar and fertilizer sources on nitrogen uptake by chilli pepper plants under Mediterranean climate. Soil Use Manag 2022;38(1):714–28. https://doi.org/10.1111/sum.12759

Enamullah SM, Rahman AFSHAN, Sahar NAJMUS, Haque SE. Detection of aflatoxin contamination and incidence of fungi associated with red chilli available in local market of Karachi, Pakistan. Pak J Bot 2022;54(6):2335–9. https://dx.doi.org/10.30848/PJB2022-6(14)

Gruber GK, De-Oliveira LB, Chiarello LM, Gonçalves MJ, Botton V. Functional and nutritional properties of chilli sauce: Propriedades funcionais e nutricionais do molho de pimenta. Braz J Dev 2022;8(9):64065–80. https://doi.org/10.34117/bjdv8n9-244

Hanif A, Ahmad S, Shahzad S, Liaquat M, Anwar R. Postharvest application of salicylic acid reduced decay and enhanced storage life of papaya fruit during cold storage. J Food Meas Charact 2020;14(6):3078–88. https://doi.org/10.1007/s11694-020-00555-5

Jouki M, Khazaei N. Effect of low-dose gamma radiation and active equilibrium modified atmosphere packaging on shelf life extension of fresh strawberry fruits. Food Packag Shelf Life 2014;1(1):49–55. https://doi.org/10.1016/j.fpsl.2013.12.001

Kamińska KM, Sura P, Wróbel M. Multidirectional changes in parameters related to sulfur metabolism in frog tissues exposed to heavy metal-related stress. Biomolecules 2020;10(4):574. https://doi.org/10.3390/biom10040574

Kantakhoo J, Imahori Y. Antioxidative responses to pre-storage hot water treatment of red sweet pepper (*Capsicum annuum* L.) fruit during cold storage. Foods 2021;10(12):3031. https://doi.org/10.3390/foods10123031

Kanwal R, Ashraf H, Sultan M, Babu I, Yasmin Z, Nadeem M, et al. Effect of 1-methyl cyclopropane and modified atmosphere packaging on the storage of okra (*Abelmoschus esculentus* L.): Theory and experiments. Sustainability 2020;12(18):7547. https://doi.org/10.3390/su12187547

Koo YM, Heo AY, Choi HW. Salicylic acid as a safe plant protector and growth regulator. Plant Pathol J 2020;36:1–10. https://doi.org/10.5423/PPJ.RW.12.2019.0295

Mi S, Zhang X, Wang Y, Zheng M, Zhao J, Gong H, et al. Effect of different genotypes on the fruit volatile profiles, flavonoid composition and antioxidant activities of chilli peppers. Food Chem 2022;374:131751.

Moshari-Nasirkandi A, Alirezalu A, Hachesu M.. Effect of *Lemon verbena* bio-extract on phytochemical and antioxidant capacity of strawberry (*Fragaria×ananassa* Duch. cv. Sabrina) fruit during cold storage. Biocatal Agric Biotechnol 2020;25:101613. https://doi.org/10.1016/j.bcab.2020.101613

Panigrahi J, Gheewala B, Patel M, Patel N, Gantait S. Gibberellic acid coating: A novel approach to expand the shelf-life in green chilli (*Capsicum annuum* L.). Sci Hortic 2017;225:581–8. https://doi.org/10.1016/j.scienta.2017.07.059

Phornvillay S, Pongprasert N, Wongs-Aree C, Uthairatanakij A, Srilaong V. Exogenous putrescine treatment delays chilling injury in okra pod (*Abelmoschus esculentus*) stored at low storage temperature. Sci Hortic 2019;256:108550. https://doi.org/10.1016/j.scienta.2019.108550

Pola W, Sugaya S, Photchanachai S. Influence of postharvest temperatures on carotenoid biosynthesis and phytochemicals in mature green chilli (*Capsicum annuum* L.). Antioxidants 2020;9(3):203. https://doi.org/10.3390/antiox9030203

Schweiggert U, Schieber A, Carle R. Effects of blanching and storage on capsaicinoid stability and peroxidase activity of hot chilli peppers (*Capsicum frutescens* L.). Innov Food Sci Emerg Technol 2006;7(3):217–24. https://doi.org/10.1016/j.ifset.2006.03.003

Solanki J, More S, Jodhani K, Patel D, Nataraj M. Efficacy of biosurfactant as a coating material for post-harvest preservation of Jamun fruit (*Syzygium cumini*). Environ Exper Bio 2022;20(1):11–23. https://doi.org/10.22364/eeb.20.02

Theofanous A, Sarli I, Fragou F, Bletsa E, Deligiannakis Y, Louloudi M. Antioxidant hydrogen atom transfer to DPPH radicals by hybrids of hyaluronic-acid components @ SiO_2. Langmuir 2022;38 (40):12333–45. https://doi.org/10.1021/acs.langmuir.2c02021

Tkaczewska J, Jamróz E, Zając M, Guzik P, Derbew Gedif H, Turek K, et al. Antioxidant edible double-layered film based on waste from soybean production as a vegan active packaging for perishable food products. Food Chem 2023;400:134009. https://doi.org/10.1016/j.foodchem.2022.134009

Topuz A, Ozdemir F. Assessment of carotenoids, capsaicinoids and ascorbic acid composition of some selected pepper cultivars (*Capsicum annuum* L.) grown in Turkey. J Food Compos Anal 2007;20(7):596–602. https://doi.org/10.1016/j.jfca.2007.03.007

Vázquez-Espinosa M, González-de-Peredo A, Espada-Bellido E, Ferreiro-González M, Barbero G, Palma M. The effect of ripening on the capsaicinoids composition of Jeromin pepper (*Capsicum annuum* L.) at two different stages of plant maturity. Food Chem 2023;399:133979. https://doi.org/10.1016/j.foodchem.2022.133979

Vinković T, Gluščić V, Mendaš G, Vinković VI, Parađiković N, Tkalec M. Phytochemical composition of ground paprika from the eastern Danube region. Poljoprivreda 2018;24(2):3–12. https://doi.org/10.18047/poljo.24.2.1

Widyastuti T, Gahayu R. Extending the shelf life of curly red chilli (*Capsicum annuum*) using $KMnO_4$. In IOP Conference Series: Earth and Environmental Science IOP Conf Ser.: Earth Environ Sci 2022;985(1):012041. https://doi.org/10.1088/1755-1315/985/1/012041

Zewdie B, Shonte TT, Woldetsadik K. Shelf life and quality of tomato (*Lycopersicon esculentum* Mill.) fruits as affected by neem leaf extract dipping and beeswax coating. Int J Food Prop 2022;25(1):570–92. https://doi.org/10.1080/10942912.2022.2053709

Zhi HH, Liu QQ, Dong Y, Liu MP, Zong W. Effect of calcium dissolved in slightly acidic electrolyzed water on antioxidant system, calcium distribution, and cell wall metabolism of peach in relation to fruit browning. J Hortic Sci Biotechnol 2017;92(6):621–9. https://doi.org/10.1080/14620316.2017.1309994