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An Integrated Approach of Hypobaric Pressures and Potassium Permanganate to Maintain Quality and Biochemical Changes in Tomato Fruits

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Abstract: Limited postharvest life of tomato fruit is due to its highly perishable nature. Hypobaric pressure is a new emerging hurdle technology usually used up to a pressure of 100 kPa for the preservation of fruits and vegetables. In this study, an integrated approach of hypobaric pressures (40 kPa and 50 kPa) and sponge-dipping of potassium permanganate ($KMnO_4$) was designed for the postharvest life extension of tomato fruits. Fruits were treated with either 400 ppm of $KMnO_4$, or 40 or 50 kPa hypobaric pressures, or their combination. Fruits without any treatment was considered as a control treatment. All groups were packaged in polypropylene trays as ready to retail and stored at room temperature at 25 $\pm$ 1 °C for 21 days. Basic quality parameters such as pH, total soluble solid, percent weight loss, percent spoilage, firmness, ethylene production rate, and color were evaluated at 3-day intervals. Results showed the application of hypobaric pressures and $KMnO_4$, either alone or in combination, provided a synergistic effect in maintaining the quality compared to the control treatment during the 21 days of storage. The highest decay was found in the control compared to the combined treatments of $KMnO_4$ + 40 kPa and $KMnO_4$ + 50 kPa. Similarly, a decrease in firmness and color values was highest in the control treatment followed by the $KMnO_4$ and 50 kPa hypobaric pressure compared to the combined treatment of $KMnO_4$ + 50 kPa. In the same way, a high ethylene production rate was observed in the control, while the lowest ethylene production rate was found in $KMnO_4$ + 50 kpa. Sensory evaluation indicated a highest score of 9 on the 9-point hedonic scale of tomato fruits. Among all groups, the combined application of 50 kPa hypobaric pressure + 400 ppm $KMnO_4$ retained the best overall quality attributes compared to all other treatments throughout the experiment; therefore, this treatment could be applied at a commercial level for tomato fruits.

Keywords: postharvest technology; ethylene production; maturity index; spoilage; color index

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1. Introduction

Tomato (*Lycopersicon esculentum*) is a very important horticultural fruit worldwide. Its production potential is obvious from its high yield and net return per unit area. In Pakistan, tomato is one of the important vegetables mostly used either in kitchen dishes or directly consumed in the form of salad. The demand for tomato consumption is increasing daily due to its high nutritious values, the country's economic growth, and an increase in the population growth [1]. China is the leading country in tomato production and produces 31.47 % of the world's production and 53% of the Asia's production, followed by the USA, India, Turkey, Egypt, and Italy [2]. Pakistan is the 37th largest country in tomato production, which counts as 0.566 million tons per annum.

Tomatoes are an important component of a healthy diet. They contain valuable phytochemicals, and their nutritional composition makes it very highly preferred by consumers worldwide [3]. Tomato is a highly perishable fruit, which loses its original quality, nutritional attributes, and sometimes wastage of the entire fruit [4]. The high perishability of tomatoes is because of their climacteric nature, which has a high respiration rate and ethylene production during the ripening process [5]. The shelf life of tomatoes could be extended by slowing the respiratory metabolism either by storing in a low temperature, or exogenous treatment, or a combination [6].

For a longer shelf-life preservation of tomatoes, synthetic chemicals have been used. For example, Tagele et al. [7] treated tomatoes with $CaCl_2$ and extended the shelf life of tomatoes to 6 days with good quality attributes. A study by Zeraatgar et al. [8] revealed that agrochemicals such as chitosan, salicylic acid, and similar treatment can best preserve the overall quality of tomatoes compared to the control. Recently, Rahman et al. [9] stated that hypobaric and 1-MCP maintained the color, ethylene, ethanol, and respiration rate in fruit, 1-MCP + 50KPa compared to the control.

However, due to safety concerns, the use of these synthetic chemicals should be minimized and other safe alternatives should be developed. Hypobaric treatment is one of the safe preservative methods used for extending the shelf life of fresh produce. Hypobaric treatment is the composition of different gases at different pressures ranging from 100 to 1000 kPa at a constant flow rate across the chamber containing fresh produce [10]. In this technology, gases are uniformly distributed and react instantly on the targeted fruits or vegetables. During hypobaric treatment, about 2–6% of the energy is required to maintain pressure in the refrigeration process. However, the pasteurization process does not need high energy to maintain the pressure [11]. Hypobaric treatment boosts the self-defense system of fruits and vegetables against external pressure and microbial attack, slows down the metabolic activities of fresh produce, and extends its shelf life. The hypobaric treatment preserved the firmness and maintained the color values and quality of the apple fruit [9]. This treatment also decreased the microbial decay of the apple fruit when stored at 20 ± 3 °C. Huan et al. [12] reported that hypobaric treatment decreased ethylene production and, thus, extended the shelf life of apples. Hypobaric treatment in combination of 1-MCP could be a better choice for preservation of fruits and vegetables (Huan et al. [13]. Quality parameters such as total polyphenols, firmness, total soluble solids, and weight loss were retained in fruits and vegetables at 25 kPa hypobaric treatment for 30 min and also showed good results in sweet cherries, grapes, strawberries, and apple fruits. In the case of strawberry fruits, six hours of hypobaric treatments were more effective against fungal decay as compared to four hours of treatment (Hashmi et al. [14]). Hypobaric pressure with 50 KPa with 1-MCP treatment on Royal Gala apple fruit for 4 h followed by cold storage retained the quality parameters (weight loss, percent spoilage, firmness, pH, TSS, and juiciness) during 120 days of storage periods (Rahman et al. [9]).

Ethylene is a ripening hormone that plays a significant role in decreasing the postharvest shelf life of ethylene-sensitive fruits and vegetables. Therefore, its removal from the surrounding atmosphere of fruits or vegetables is very important. Potassium permanganate ($KMnO_4$) is an ethylene-scavenging compound that is easily available in various forms. $KMnO_4$ delays the ripening process in horticulture produces through its oxidizing reactions mechanisms. One of the key roles of this compound is to remove the atmospheric ethylene by converting it into CO_2 and H_2O, thus delaying the softening process and increasing the postharvest shelf life of fruits ([15] and Köstekli et al. [16]).

While preserving the postharvest life of fruits and vegetables, packaging is one of the basic needs and requirements to hold the products, avoid water loss, protect from environmental hazards, and provide ease in carrying and displaying products in the markets. Proper selections of polymeric materials are very important to meet the requirement of the packaged product to get maximum protection and shelf-life extension. Clarity, antifogging, water proofing, temperature, permeation, mechanical, and other qualities must be considered, while selecting polymeric films for packaging purposes, particularly for fresh produce [17,18]. Khan et al. [18] used various polymeric films on the shelf-life preservation of longan fruits treated with propyl disulfide from the neem plant. The shelf life of longan fruit treated with thymol essential oil was also extended using polyethylene packaging materials [19].

The postharvest life of tomatoes is very limited, due to high moisture content, fungal growth, production of high ethylene production rate at the climacteric stage and, autolysis. No literature was found on the maximum postharvest storage of tomatoes; therefore, this study was conducted to preserve and maintain the postharvest quality of tomatoes with different hypobaric treatments. To minimize the production rate of high ethylene, tomatoes were also treated with potassium permanganate ($KMnO_4$) either alone or in combination with different hypobaric treatments. Various basic quality parameters were analyzed and reported in this paper.

2. Materials and Methods

2.1. Samples and Treatments

About 25 kg of freshly harvested tomatoes (*Solanum Lycopersicum*) cv. Rio grande were obtained from the field of in Tarnab, Peshawar, located at 71.680684° E longitude and 34.2206097° N latitude, cultivated in loam soil type with composition of 38% sand, 44.5% silt, and 17.5% clay. Cultural methods were used for cultivation and harvesting tomatoes. Fruits were selected based on visual evaluations and transported in normal conditions to the laboratory. Tomatoes having uniform color, size, and shape without any defects were selected for the experiment and divided into 6 groups (treatments). The first group without any treatment was used as a control. The second group was treated with 400 ppm solution of $KMnO_4$, the third group was treated with 40 kPa of hypobaric pressure, the fourth group was treated with 400 ppm + 40 kPa of hypobaric pressure, the fifth group of tomato fruits was treated with 50 kPa hypobaric pressure, and the last group was treated with 400 ppm + 50 kPa of hypobaric pressure. A total of 21 trays were prepared for each group with 3 fruits in each tray, which means that on every respective day of analysis, 3 trays were opened from each group. All the trays in each group were packaged in polypropylene polymeric trays to validate the display in retail markets in real situations, were stored at 25 ± 1 °C for 21 days, and basic quality parameters were evaluated at every 3 days interval.

2.2. Hypobaric Treatment

For the hypobaric treatment, tomatoes were kept in the hypobaric chamber and treated with 40 and 50 kPa pressures for 2 h each according to the method of Hashmi et al. [20].

2.3. Potassium Permanganate Treatments

Potassium permanganate ($KMnO_4$) solution (400 ppm) was prepared and applied according to the method of Mujtaba et al. [21]. Briefly, the sponge was cut into one-inch cube pieces, dipped in $KMnO_4$ solution, and kept in the packaging trays containing tomatoes in such a way that the sponge was not in direct contact with tomatoes. All the packages were hermetically sealed to avoid any air exchange from outside.

2.4. Ethylene Production Rate

The ethylene production rate was measured according to the method of Lerud et al. [22]. Briefly, tomatoes were kept in a 1 L jar and hermetically sealed. A small nozzle was attached in the lid of each jar for withdrawing ethylene gas. A gas sample was taken using a 10 cc syringe and injected into an ethylene detector (Model F-900, Felix Instrument, Camas, WA, USA). Data were recorded in ppm using three replicates of each treatment.

2.5. Weight Loss

Weight loss in tomatoes was calculated from the difference in weight at day 1 and on each respective day of quality evaluation, using the following formula. Three trays were opened from each group on respective days for analysis. Weight loss was measured with the following formula.

$$\text{Weight loss (\%)} = \text{initial weight} - \text{final weight} \times 100 \quad \text{initial weight} \tag{1}$$

2.6. Color (L^*, a^*, and b^*) Values

The color (L^*, a^*, and b^*) values of each tomato in all packaging trays were determined through a Hunter colorimeter PCE-CSM 2 (PCE. Instruments Meschede Germany) by following the method of Khan et al. [23]. Chroma and hue angles values were also calculated. A total of 3 fruits from each replicated trays were used for color value determination.

2.7. Spoilage (%)

The spoilage was evaluated based on the physical and visual appearance of decayed tomatoes. Any fruits having visible decay symptoms were considered decayed. The number of decayed tomatoes were counted in each package, and percent decay was calculated according to Khan et al. [18] with the following formula

$$\%\text{Spoilage} = \text{Decayed tomatoes} \times 100/\text{Total tomatoes} \tag{2}$$

2.8. Firmness (N)

Tomato firmness was determined by a penetrometer (Model-Lutron, FR.5120 enterprises, Taipei city, Taiwan), using the method of Hashmi et al. [20]. Both sides of each fruit were penetrated with a penetration prob up to a depth of 11 mm. Three tomatoes in each tray were subjected to the penetrometer, the average was taken and used for statistical analysis, and results were expressed in newton (N).

2.9. pH and TSS (Brix)

The pH and TSS in tomatoes were measured according to the method of AOAC [24]. Three tomatoes from each tray were ground and filtered through muslin cloth to obtain a clear juice. pH was determined using a digital pH meter (WTW Inolab). Total soluble solids were determined by a refractometer (Atago, Tokyo, Japan). pH and TSS were determined in triplicate.

2.10. Statistical Analysis

All the results were statistically analyzed by completely randomized design (CRD) with 2-factorial design and the mean were separated by least significant difference (LSD) at $p \leq 0.05$ using Statistix 8.1® software, Tallahassee, U.S. State of Florida.

3. Results

3.1. pH

The pH values of tomato fruits increased with storage time (Figure 1). The pH value in the control sample was increased from 3.8 on day 0 to 4.32 on day 21. The highest increase in pH values was observed in the control treatment. Among the other treatments, $KMnO_4$ in combination with 40 and 50 kPa maintained the pH values in tomatoes fruits (Figure 1). The treatment of $KMnO_4$ combined with 50 kPa hypobaric pressure delayed the ripening of the tomato and maintained the quality attributes during the 21 days of storage. Similar results of increasing the pH values of tomato fruits were also observed by Mujtaba et al. [21] when tomato fruits were treated with $KMnO_4$. An increase in pH values is the indication of the tomato ripening and the degradation of organic acid starts, which decreases the acidity and affects the hydrogen ion concentration of the fruits [25,26]. Salamanca et al. [27] reported that $KMnO_4$ as an ethylene scavenger delayed the acid degradation process in tomato fruits stored at 18 °C. Mujtaba et al. [21] stated during elimination of ethylene by $KMnO_4$, a significant delay in the ripening process in terms of acid consumption was observed, which maintained the quality of the tomato fruits. Wills and Ku [28] showed a delay of up to 25% in acidity after 14 days of storage when tomatoes were treated with 1-MCP.

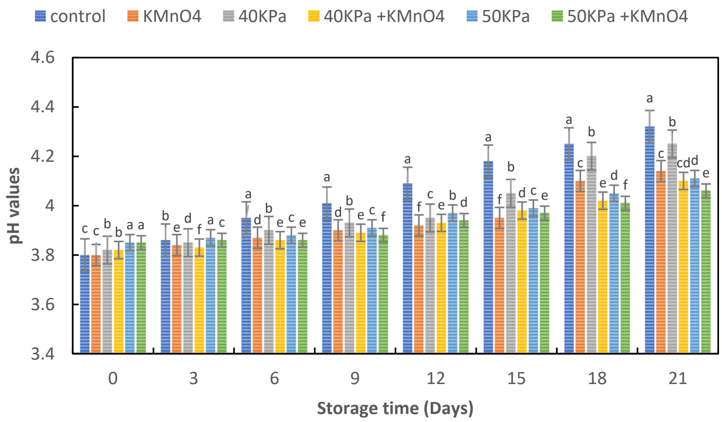

Figure 1. The pH values of tomato fruits treated with hypobaric pressures, $KMnO_4$, and their combination during storage at 25 ± 1 °C. Different letters show significant differences among treatments. $p \leq 0.05$, (n = 3).

3.2. Total Soluble Solids (Brix)

Figure 2 shows the TSS values of tomato fruits. No clear difference was observed in the TSS values in all treatments on day 0. When the storage time is extended, changes in the TSS values become obvious, and more significantly in the control treatment. Individual treatments of 40 and 50 kPa hypobaric pressures relatively maintained high TSS values, whereas a slight change in the TSS values was observed in the combined treatments of hypobaric pressures and $KMnO_4$. Changes in the TSS contents could be due to the conversion of starch into sugar [29]. Results in this study indicate that a decrease in the TSS contents in the hypobaric pressure treatments could be due to its strong effect on the breakdown of complex carbohydrates into simple sugar [30]. Retaining the TSS values in the $KMnO_4$ treatment could be due to the production of carbon dioxide, which controls the respiration rate of the tomato and consequently delays the maturity. As Azzolini [31] stated, that increase in TSS is directly related to the maturity stages, particularly the ripening stage where hydrolysis of polysaccharides occurs and leads to the progressive increase in the sugar content.

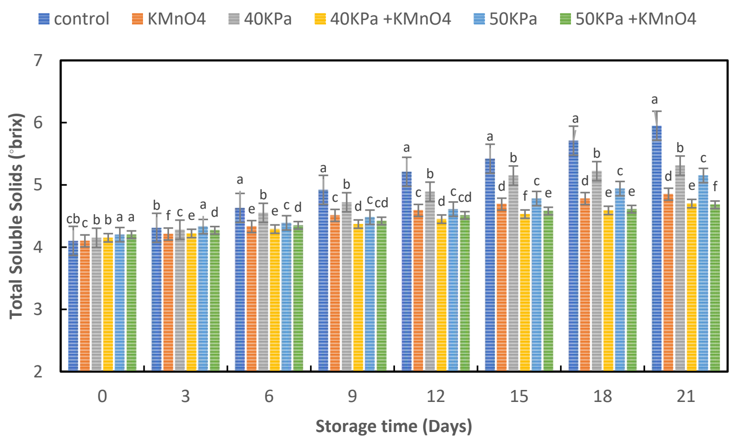

Figure 2. TSS values of tomato fruits treated with hypobaric pressures, $KMnO_4$, and their combination during storage at 25 ± 1 °C. Different letters show significant differences among treatments. $p \leq 0.05$, (n = 3).

3.3. Weight Loss (%)

Weight loss is one of the major quality attributes of fresh commodities as it affects the texture, weight, appearance, overall acceptability, and, consequently, purchasing decision of the consumers.

Weight loss of tomato fruits is shown in Figure 3. Weight loss was increased with storage time in all treatments. Maximum weight loss was found in the control treatment, while the lowest weight loss was observed in $KMnO_4$ + 50 kpa. An increase in weight loss could be due to the high respiration rate of the tomato's fruits which increases the transpiration rate from the fruits surface [32]. A maximum percent increase was observed in the control treatment. Treated fruits have relatively low weight loss compared to the control, which shows that $KMnO_4$ and hypobaric pressure had an effect in controlling the weight loss of tomato fruits. Roth [33] stated that $KMnO_4$ degrades dissociates ethylene into water and CO_2, and creates a humid environment in a closed package. Potassium permanganate reduces the rate of ripening and transpiration [34]. Tomato fruits are very susceptible to rapid water loss probably due to their thin skin and very low resistance to mass transfer [35]. Salamanca et al. [27] stated that $KMnO_4$ in combination with zeolite was effective in postharvest preservation of tomato fruits (cv Chonto), and lower weight loss and higher firmness were obtained compared to the control.

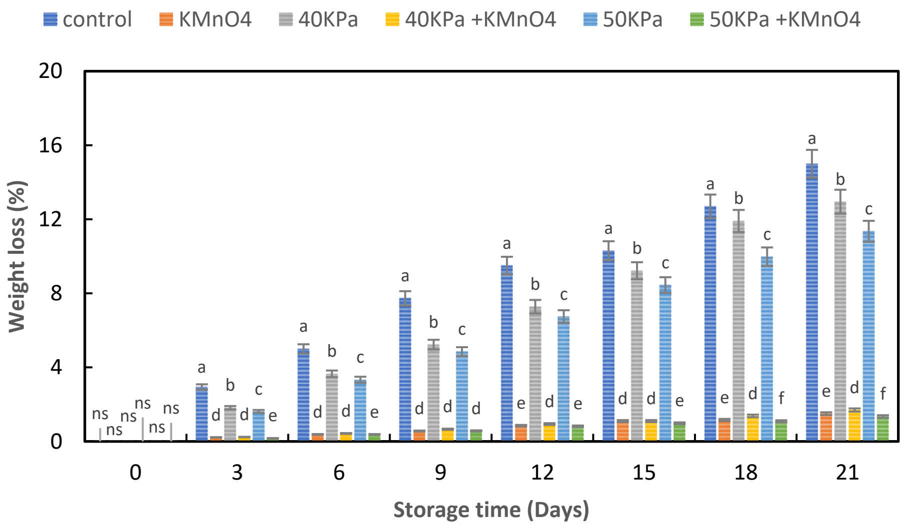

Figure 3. Weight loss (%) of tomato fruits treated with hypobaric pressure, $KMnO_4$, and their combination during storage at 25 ± 1 °C. Different letters show significant differences among treatments. $p \leq 0.05$, (n = 3).

3.4. Percent Spoilage

Tomatoes are highly perishable in nature due to a large amount of free and bound water available for the growth of various microorganisms. Application of $KMnO_4$ with 40 or 50 kpa hypobaric pressures effectively inhibited the microbial growth compared to their individual treatments and the control. Among all treatments, the highest decay was found in the control on day 21 as compared with combined treatments, which were $KMnO_4$ + 40 kPa and $KMnO_4$ + 50 kPa as shown in Figure 4. Although $KMnO_4$ individually reduced decay in tomato fruits compared to the individual effect of 40 or 50 kPa hypobaric pressures; however, when $KMnO_4$ was combined with these hypobaric pressures, a synergistic effect was observed in the inhibition of tomatoes decay. Our results are in agreement with the work of Huan et al. [13] who reported that hypobaric treatment (25 ± 5 kPa) significantly reduced the fungal decay in kiwi fruits and maintained the quality during storage.

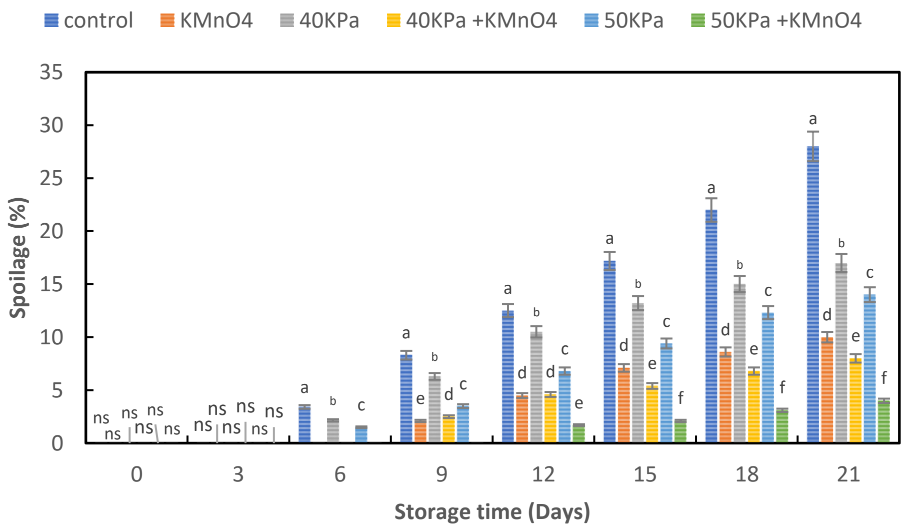

Figure 4. Spoilage (%) of tomato fruits treated with hypobaric pressures, $KMnO_4$, and their combination during storage at 25 ± 1 °C. Different letters show significant differences among treatments. $p \leq 0.05$, (n = 3).

3.5. Firmness (N)

The firmness of tomatoes is directly associated with the ripening process [36]. As the ripening process of tomato fruits starts, the firmness of tomatoes starts to decline. In the beginning, the firmness of the samples was 26 N (control), which was decreased to 11 on day 21 (Figure 5). Similarly, the firmness of combined samples $KMnO_4$ + 40 kPa and $KmnO_4$ + 50 kPa were 24 N and 23.5 N, which were decreased to 18 N and 20 N, respectively (Figure 5). Storage time and temperature have a significant role in the softening phenomenon of tomato fruits. The firmness of tomato fruits varies with the environmental condition, variety, and storage condition, even the variability occurs from 20–25% in the same cultivar and similar storage conditions. For the consumer's acceptance of fruit firmness, softening of the fruits is a very important quality attribute [37]. The possible mechanism of firmness loss could be due to the solubility of pectin and hemicelluloses, and the disruption of the cell wall of tomato fruits [38]. Another reason for the high firmness of tomato fruits in this study could be due to the application of $KMnO_4$ either alone or in combination with hypobaric pressures as $KMnO_4$ degrades ethylene into carbon dioxide and water that blocks the synthesis of endogenous ethylene. In addition, $KMnO_4$ works against the *Botrytis cinerea* fungi, which causes a very big loss in the firmness of tomatoes [39]. Freitas et al. [40] stated that the application of different concentrations (0, 0.250, 0.375, and 0.500 g) of $KMnO_4$ on sapodilla fruits significantly increased the fruit shelf life for 5 days at room temperature by retarding the loss firmness.

3.6. Color (L*, a*, b*) Values

Results showed that the lightness (L*) values of tomato fruits decreased with storage time. A highest decrease in L* value was recorded in the control treatment followed by the individual treatment of 40 and 50 kPa hypobaric pressures, while the lowest decrease in L* value was recorded in the combined treatment of $KMnO_4$ + 50 kPa, followed by $KMnO_4$ + 40 kPa, and the individual treatment of $KMnO_4$ (Figure 6A). Among all treatments, the $KMnO_4$ + 50 kPa treatment effectively maintained the L* values. When L* values data were compared with respect to days, L* values were highest at day 0, which were significantly decreased on day 21. The combined treatment showed a significant difference and presented the best results compared to the control treatment (Figure 6A). Color is also an important external characteristic of tomato fruits. It is also used as an indicator in tomato ripening [41].

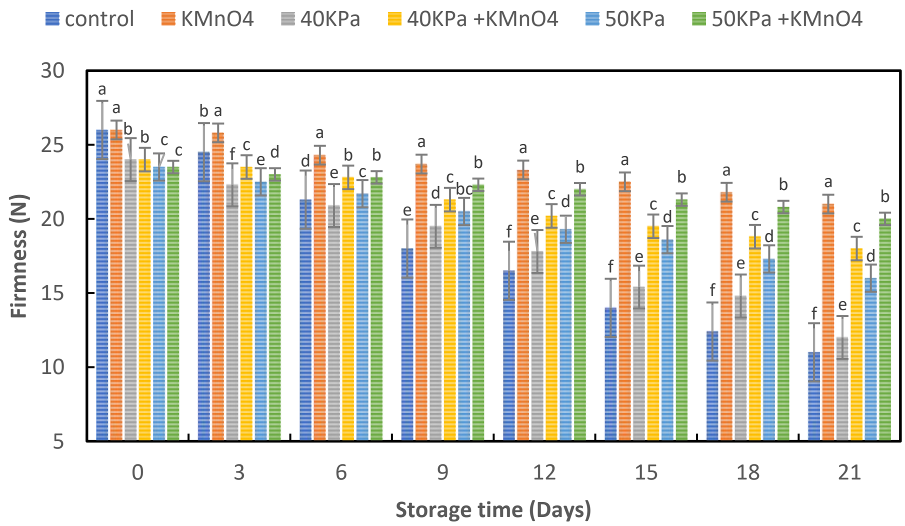

Figure 5. Firmness (N) of tomato fruits treated with hypobaric pressures, $KMnO_4$, and their combination during storage at 25 ± 1 °C. Different letters show significant differences among treatments. $p \leq 0.05$, (n = 3).

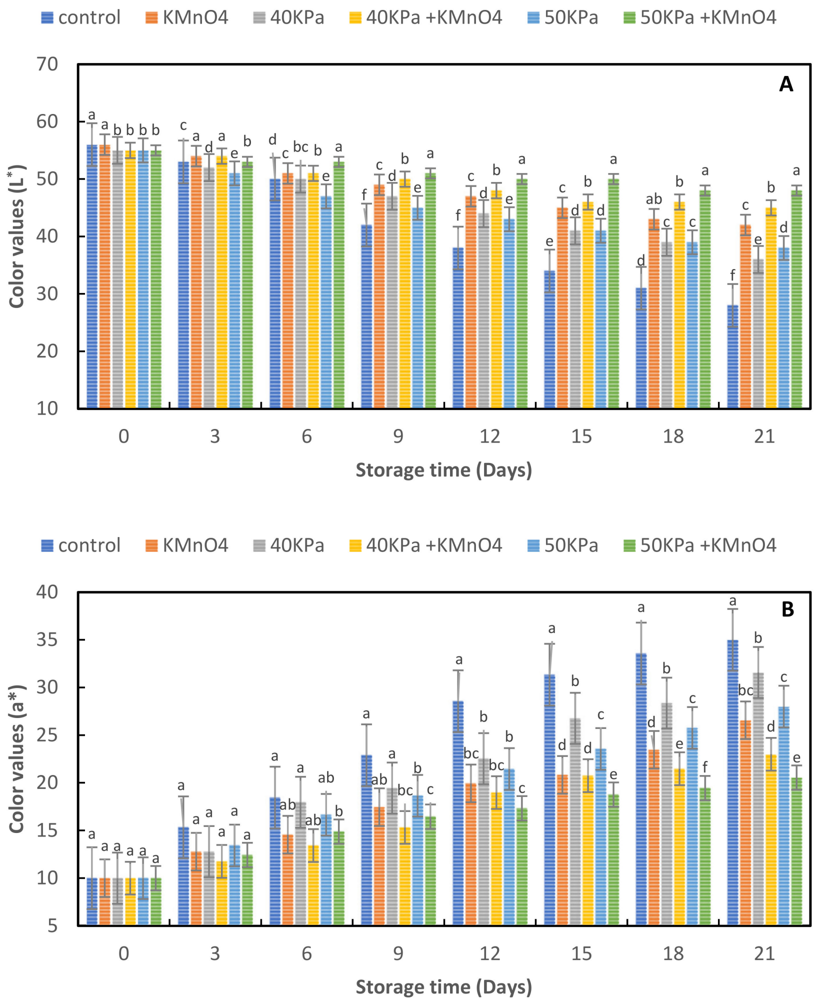

Figure 6. *Cont.*

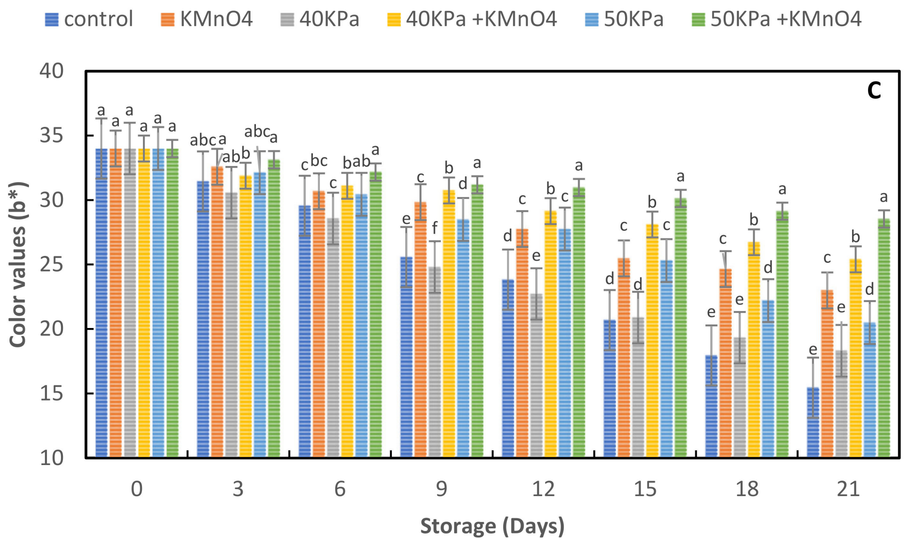

Figure 6. Color values, L * (**A**), a* (**B**) and b* (**C**) of tomato fruits treated with hypobaric pressures, $KMnO_4$, and their combination during storage at 25 ± 1 °C. Different letters show significant differences among treatments. $p \leq 0.05$, ($n = 3$).

The a* values indicate the red color of tomato fruits. The a* values increased gradually with the storage time extension: a* values increased from 10 on day 0 to 35, 26.55, 31.58, 23, 28, 20.55 on day 21 in the control, $KMnO_4$, 40 kPa, $KMnO_4$ + 40 kPa, 50 kPa, and $KMnO_4$ + 50 kPa, respectively (Figure 6B). The highest a* values were obtained in the control treatment, while the lowest values were obtained in the combined treatment of $KMnO_4$ + 50 kPa.

The b* values indicate the yellow color of tomato fruits. Figure 6C shows that the b* value decreased during storage, particularly in the control treatment where b* values decreased from 34 (day 0) to 15.45 (day 21). Among all other treatments, the highest b* values were observed in the combined application of $KMnO_4$ + 50 kPa throughout the storage time. Lycopene is a red pigmented product in tomato fruits. An increase in the a* values is associated with lycopene contents in the tomato fruits. All these changes in color values of L*, a*, and b* occurred with the maturation of tomatoes. During this process, chlorophyll degrades and synthesis of carotenoids (lycopene and β-carotene) occurs, which consequently changes the color of the fruits [42]. Tohge et al. [43] reported that about a 10–14-fold increase in carotenoid content occurs during the ripening stage. In this current study, combined treatment of 400ppm $KMnO_4$ and hypobaric pressures, particularly $KMnO_4$ + 50 kPa, maintained the L*, a*, and b* values in tomato fruits. This could be attributed to the effect of $KMnO_4$, as Sammi and Masud [5] found that $KMnO_4$ incorporated in the plastic films was effective in delaying the ripening and color development. Wabali and Esiri [44] stated that among the different concentrations (2.5 ppm, 5.0 ppm, 7.5 ppm, 10.0 ppm, 12.5 ppm, and 15.0 ppm), 5 ppm of $KMnO_4$ effectively maintained the color values and extended the shelf life of tomatoes fruits with overall good quality attributes.

3.7. Ethylene Production Rate (μmol kg^{-1} hr^{-1})

Ethylene is the main ripening hormone, and the ripening process in the climacteric fruit is regulated by ethylene [45]. In this experiment, the ethylene production rate and associated quality changes in tomato fruits were measured because fruits were treated with $KMnO_4$ as $KMnO_4$ is an ethylene scavenging compound. The ethylene production rate increased when the storage period was prolonged (Figure 7). The highest ethylene production rate was found in the control treatment, while the lowest ethylene production rate was found in $KMnO_4$ + 50 kpa. The ethylene production rate at day 0 was 0.08 ppm, which was increased to 2.75 ppm at day 21 in the control treatment. Similarly, an increasing trend was observed in all treatments; however, the combined treatment minimized the ethylene production rate (Figure 7). It was found that tomato fruits treated with $KMnO_4$ only or in combination with hypobaric pressures had a very low ethylene production rate compared to the control or only hypobaric pressures. This low production rate of ethylene could be attributed to the reaction of $KMnO_4$, which converts ethylene into carbon dioxide and water [16].

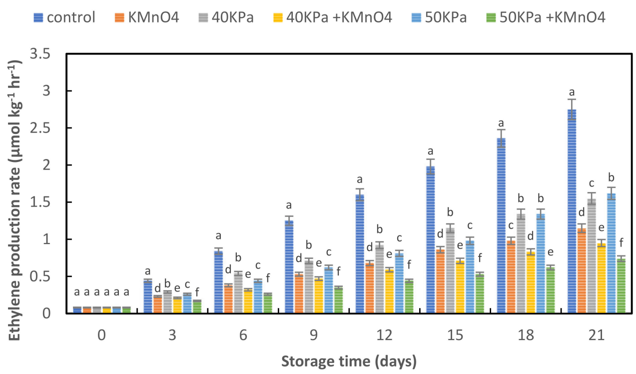

Figure 7. Ethylene production rate of tomato fruits treated with hypobaric pressures, $KMnO_4$, and their combination during storage at 25 ± 1 °C. Different letters show significant differences among treatments. $p \leq 0.05$, (n = 3).

4. Conclusions

Tomato fruits have a very short postharvest life. In this study, a new technique of an integrated approach of hypobaric pressures was applied either alone or in combination with $KMnO_4$. All treatments maintained a very good quality of tomato fruits during 21 days of storage at room temperature compared to the control. However, the combination of 400 ppm $KMnO_4$ with 50 kPa hypobaric pressure provided a synergetic effect and extended the shelf life with good overall quality attributes. This treatment maintained color values, resulted in a low ethylene production rate, low microbial decay, and maintained other quality features of tomato fruits. Therefore, the combination of 400 ppm $KMnO_4$ with 50 kPa hypobaric pressure could be recommended for commercial application of tomato fruits.

Author Contributions: Conceptualization, A.M., M.R.K. and K.S.D.; methodology, A.M and H.K.; software, I.K., S.K. and M.I.; validation, K.S.D.; formal analysis, A.M., H.K.; resources, K.S.D., I.K. and M.R.K.; data curation, I.K. and F.H.; writing—original draft preparation, A.M.; writing—review and editing, M.R.K. and F.H.; visualization, A.B. and M.A.; supervision, K.S.D.; project administration, K.S.D. All authors have read and agreed to the published version of the manuscript.

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