horticulturae

Article

Effect of Simulated Vibration and Storage on Quality of Tomato

Pankaj B. Pathare * and **Mai Al-Dairi**

Department of Soils, Water and Agricultural Engineering, College of Agricultural & Marine Sciences,
Sultan Qaboos University, Muscat 123, Oman; s124911@student.squ.edu.om
* Correspondence: pankaj@squ.edu.om or pbpathare@gmail.com; Tel.: +968-2414-1222

Abstract: The influence of simulated transport vibration and storage conditions for 10 days on tomato fruits quality (color, weight, firmness, total soluble solids, and headspace gases) were investigated. Better kinetic models for color changes, weight loss, and firmness of stored tomato fruits were selected. Tomato fruits were divided equally into two main groups where the first one was subjected to vibration at a frequency of 2.5 Hz for two hours and the other group was set as a control (with no vibration stress). Both tomato groups were stored for 10 days at 10 °C and 22 °C storage conditions. The results showed a reduction in total soluble solids, yellowness, weight, lightness in the tomato fruits subjected to vibration at 22 °C storage condition. Ethylene and carbon dioxide increased by 124.13% and 83.85% respectively on the same condition (22 °C). However, storage at 10 °C slowed down the investigated quality changes attributes of both tomato groups (vibrated and control) during storage. The weight loss change kinetics of both tomato groups at both storage temperatures were highly fitted with a zero-order kinetic model. Color and firmness kinetic changes of tomato groups stored at both conditions were described well by zero and first order kinetic models. To validate the appropriateness of the selected model, lightness, redness, yellowness, and firmness were taken as an example. The study revealed that the vibration occurrence and increasing storage temperature cause various changes in the quality attributes of tomatoes.

Keywords: quality; kinetic model; tomato; simulated vibration; storage; transport

Citation: Pathare, P.B.; Al-Dairi, M. Effect of Simulated Vibration and Storage on Quality of Tomato. *Horticulturae* **2021**, *7*, 417. https://doi.org/10.3390/horticulturae7110417

Academic Editors: Maria Dulce Carlos Antunes, Custódia Maria Luís Gago and Adriana Guerreiro

Received: 31 August 2021
Accepted: 18 October 2021
Published: 20 October 2021

Practical Application

The practical application of this research is the understanding of the main causes of damages and quality changes of tomatoes due to vibration generated from the simulated transport at a particular frequency. The use of optimal storage temperature and the other proposed temperature can help to minimize the resulted damages in tomatoes. Improving refrigeration storage conditions in the supply chain of tomatoes is required and very essential to reinforce the quality and shelf life of the product. The mathematical models used in our research with the presence of vibration and control data, storage temperatures, and storage durations helped to predict the effect of simulated vibration and control groups on the quality of tomatoes during the experimental time. Such valuable data can help to discover different strategies and technologies to minimize the deterioration of fresh produce like tomatoes during the supply chain.

1. Introduction

Tomato fruit (*Lycopersicon esculentum*, Mill) is one of the most common and significantly grown fresh produce worldwide and ranked second after potato in terms of area and amount of production as recently reported by FamuyİnÍ and Sedara [1]. It is a vital source of nutrients and different beneficial minerals and considers as a source of income in most developing countries. The quality of any agricultural product is a significant factor for both the consumers and producers. The quality of tomatoes is highly categorized by weight, color, firmness, and flavor [2]. Tomatoes are climacteric fruits and their physiological attributes make them highly delicate agricultural products [3]. Wu and

Wang [4] highlighted that tomatoes can be affected by postharvest factors like storage, handling, and transportation, etc. Besides, Cherono et al. [5] stated that postharvest losses in tomatoes are as high as 40%.

The quality of fresh produce is reduced during transportation due to biological and physical damages/changes caused by vibration [6]. Vibration generated from transportation caused different external and internal damages to fresh produce. Interior damage is most difficult to recognize via consumers as reported by Wei et al. [7]. Besides, vibration can consider as a critical problem influencing fruit and vegetable sugar content [8], ripening, firmness, browning, core breakdown [7], color redness [4], and headspace gases (O_2, CO_2, C_2H_4) [9]. Walkowiak-Tomczak et al. [10] found that the mechanical vibration of the simulated transport reduced the firmness of 'Gala' and 'Idared' apple by 9 and 13%, respectively, after 14 days of storage. Jung et al. [11] revealed that vibration stress increased the amount of ethylene concentration of packaged grapes (15.3 nL/g·h) compared to the initial stage, while about 9.8 nL/g·h for the packaged grapes with no vibration stress. Tao et al. [12] stated that the vibrated mushrooms showed higher changes in color browning index (89.4) compared to the controls (56.2). Besides, Xu et al. [13] reported that the soluble solids content of blueberries vibrated for 12, 24, and 36 h reduced by 12.9, 21.4, and 28.6%, respectively, and firmness decreased by 28.6, 57.1, and 78.6%, respectively, comparing with the control one. Vibration occurrence can induce both weight and water loss of fresh produce that led to shriveling, which is one of the major physical alterations and cause a direct effect on appearance. Therefore, increasing flesh of fresh tissues [7]. Also, Tao et al. [12] reviewed that mechanical damages generated due to vibration can accelerate the weight loss % in fresh produce, which directly affects the marketability of produce. Jung et al. [11] reported a weight loss of 15% in the vibrated grape group compared to 9% in the control grape group after 30 days storage period. The effect of transport vibration has been studied in the quality of different fresh produce including tomato fruit [4,14], kiwifruit [7], grape fruit [11], broccoli [15], strawberry [16] and mushroom [17].

The quality of fresh produce like tomatoes is highly correlated with storage temperature and storage time [5]. Storage temperature can greatly affect tomato firmness, color, and flavor [18]. Increasing the storage temperature of products can increase the processes of respiration, transpiration, and ethylene rates resulted in a high weight loss percentage [19]. Arah et al. [20] reviewed that tomato fruits contain a high amount of moisture contents; thus, it is difficult to keep and store them at ambient temperature for a long period. Recently, Al-Dairi et al. [2] recorded 16.60% weight loss on tomatoes stored for 12 days at ambient temperature. Low storage temperature condition is considered as a major factor applied for maintaining the quality of postharvest attributes of tomatoes. Furthermore, data on postharvest characteristics of fresh produce are significant and required as an input used for models to predict postharvest behavior and attributes [21].

Kinetic modeling is an essential tool for predicting and controlling the quality attributes alterations in fresh produce [22,23]. It has been highlighted that kinetic modeling has been applied to identify the changes in fresh produce quality characteristics like firmness, color parameters, weight [24], pigments, sugars, and acids [25]. The mathematical modeling depends on the reaction rate like zero-order kinetic models, first-order kinetic models, and higher was applied on different fresh produce [22,24].

This study was carried out to explore the influence of 2 h of simulated transport vibration and storage at 10 °C and 22 °C on tomato's quality attributes like weight loss, color parameters, firmness, TSS, and headspace gases for 10 days storage period. Kinetic models were also applied as a new contribution for predicting the weight loss, color, and firmness kinetic on the stored tomato groups as a function of time.

2. Materials and Method

2.1. Plant Sample and Vibration/Storage Treatments

'Roma' variety tomato fruits packaged in a recycled plastic container with a dimension of (365 × 255 × 155 mm) were purchased from the market and transported to Postharvest

Technology Laboratory of Sultan Qaboos University, Oman. The selected samples (n = 63) were similar in color, size, weight (177 ± 0.02 g), firm state, and free of defects and blemishes. Tomato fruits were divided equally into two main groups where the first one was subjected to vibration at 2.5 Hz frequency for two hours and the other group stressed no vibration stress.

The vibrated group were exposed to vibration using an orbital shaker (model: SM25, Edmund Bühler GmbH, Schleswig-Holstein, Germany) [16] to simulate the vibration generated during fresh produce transportation at 2.5 Hz frequency for 120 min at a speed of 150 revolutions per minute (r/min) (205 km distance). The plastic container was tightly fixed in the top of the shaker and 3-axis vibration/acceleration data loggers (Model: OM-VIB101, Spectris plc, Connecticut, Norwalk, CT, USA) were placed vertically inside the container (bottom, middle and top) to record the generated vibration (every 1 s) during simulated transport from three different positions. The resulted vibration signals were later transformed to a personal computer and a shock application (Vibration data logger v2.3) was applied for time-domain vibration analysis of signals. Also, a histogram was used to identify the peaks number generated per accelerometer fixed on each location during the simulated transport experiment.

After conducting the simulated vibration experiment, tomatoes with and without vibration stress were divided equally into two groups at 22 ± 1 °C (65 ± 5% RH) and 10 ± 0.5 °C (95 ± 1% RH). Further objective evaluations of tomato fruit were carried out such as weight loss, firmness, color, total soluble solids (TSS), and headspace gases to study the influence of vibration/control treatments and two storage conditions on the quality of tomatoes at two days intervals for 10 days. For day-0 analysis, three tomato fruits with no vibration were analyzed for all previously mentioned analyses. Besides, daily observations of bruising were recorded. In the current paper, a total of 3 tomato fruits replicates were utilized for each treatment.

2.2. Physical and Physiological Quality Analysis

2.2.1. Weight Loss%

A batch of three tomato fruits for each treatment was weighed on day 0 and the weight loss percentage was recorded on days 2, 4, 6, 8, and 10, relative to day 0.

2.2.2. Color Measurements

The color values of tomato fruits were measured using a computer vision system (Figure 1). A total of 5 readings were taken per sample for color measurements during the experiment at 2 days intervals (60 per day). The system includes a cardboard box utilized to cover the entire system and to avoid the backscattering effect. A lighting system including two long fluorescent lights (36 W) (Model: Dulux L, OSRAM, Milano, Italy) was placed above the sample at an angle of 45°. An RGB digital camera (Model: EOS FF0D, Canon Inc., Tokyo, Japan) was fixed in the top of the cardboard box at 26 cm from the sample. The digital camera involves a remote shooting software EOS Utility used to acquire the image in the maximum required resolution. All captured images were transferred to a personal computer and stored in JPG format for subsequent analysis. ImageJ software (v. 1.53, National Institute of Health, Bethesda, MD, USA) was performed for image processing [6]. All obtained RGB values were transformed to CIEL*a*b* color coordinates. The L* value refers to darkness (0) and lightness (100), a* value is used to donate redness (+) and greenness (-), and the value of b* denotes yellowness (+) and blueness (-). The total color difference (TCD) (Equation (1)) from tomato samples was calculated. Chroma (Equation (2)), hue angle (Equation (3)), and tomato color index (CI) (Equation (4)) indicating color intensity, purity, and red color development index, respectively were also computed [26] as follow:

$$\Delta E* = \sqrt{\Delta a*^2 + \Delta b*^2 + \Delta L*^2} \quad (1)$$

$$Chroma = \sqrt{a*^2 + b*^2} \tag{2}$$

$$Hue^\circ = tan^{-1}\left(\frac{b^*}{a^*}\right) \tag{3}$$

$$CI = \left(\frac{a^*}{b^*}\right) \tag{4}$$

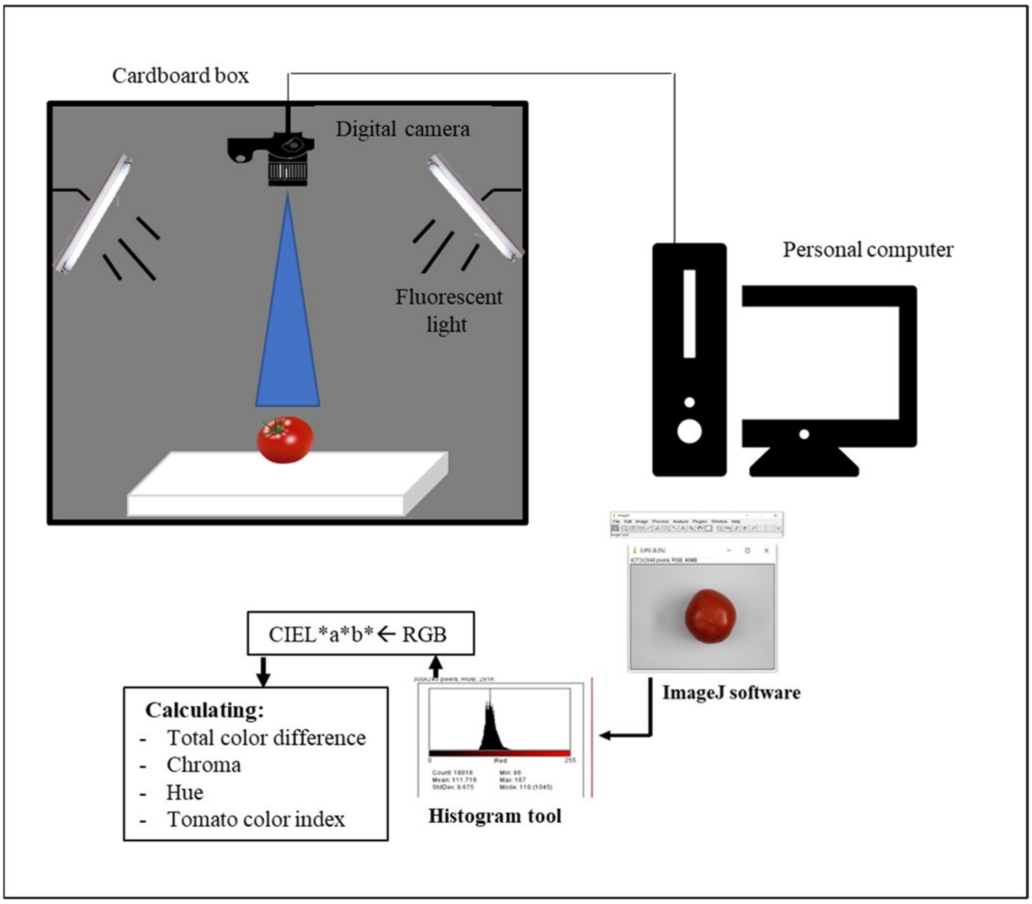

Figure 1. A schematic diagram of computer vision system.

2.2.3. Firmness

To measure the force (N) needed to puncture the tomato surface, a digital fruit firmness tester (Model: FHP-803, L.L.C., Franklin, ME, USA) was used. Both sides were measured in each tomato sample at two days intervals.

2.2.4. Total Soluble Solids (°Brix)

Tomatoes juice was extracted and then analyzed by utilizing a digital refractometer (Model: PR-32 α, ATAGO Co., Ltd., Tokyo, Japan). Clear and pure drops of tomato juice were added to the prism surface of the refractometer and the readings were taken and expressed as °Brix.

2.2.5. Headspace Gases (CO_2, O_2, and C_2H_4)

After the vibration treatment, eight plastic food containers (2.6 L) were prepared as gas collection containers. A total of 6 tomatoes (968.3 ± 25.2 g) were placed inside each container. Oxygen (O_2) and carbon dioxide (CO_2) concentrations were measured using O_2/CO_2 analyzer (Model: 90 2D, Quantek Instruments, Inc., Grafton, Australia). Ethylene (C_2H_4) (ppm) was determined using an ethylene detector (Model: SCS 56, Fricaval89, Valencia, Spain). Both instruments include a needle that is plunged inside the containers and an electronically timed pump used to pull the needed amount of gases for further analysis. Besides, two replicates were used per treatment to determine O_2, CO_2 (%), and C_2H_4 (ppm) inside the containers for two days intervals.

2.3. Kinetic Model

To determine the physical quality changes of vibrated and non-vibrated tomatoes stored at different storage temperature conditions as a function of time, a kinetic model was applied. The rate of quality change factor was explained by (Equation (5)) [27]:

$$\frac{dC}{dt} = -kC^n \tag{5}$$

where k is the kinetic rate constant at a temperature T, C is the quality factor concentration at time t, and n is the order of the reaction. Most time-dependent relationships for most food materials are likely to be well fitted with the zero-order kinetic model (Equation (6)) or the first-order kinetic model (Equation (7)) follow [28]:

$$C = C_0 \pm kt \tag{6}$$

$$C = C_0 \times \exp\,(\pm kt) \tag{7}$$

where C_0 is the initial quality parameter value, C is the quality parameter value at a time and t is the time of storage. Regression analysis such as reduced chi-square (X^2) (Equation (8)), determination of coefficient (R^2) (Equation (9)), and root mean square error (RMSE) (Equation (10)) were done as the main standard to choose the best fit of the studied kinetic models to the current experimental data. Also, the model that effectively fitted tomato fruits quality parameters was defined with the maximum R^2 and lowest X^2 and *RMSE*. Besides, the following formulas were applied for the estimations of the parameters [23]:

$$X^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N-n} \tag{8}$$

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2}{\sum_{i=1}^{N}\left(MR_{pre} - MR_{exp,i}\right)^2} \tag{9}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{exp,i}\right)^2} \tag{10}$$

where, $MR_{pre,i}$ and $MR_{exp,i}$ are the ith predicted and experimental values of the quality parameters and MR_{pre} is the average values of predicted quality parameters, n is the numbers of constant model and N is the number of observations. To validate the appropriateness of the selected model, some quality attributes were taken as an example.

2.4. Statistical Analysis

SPSS 20.0 (International Business Machine Crop., New York, NY, USA) was applied to study the influence of vibration/control treatments as well as storage temperature conditions (10 °C and 22 °C) on the physical and physiological attributes of tomatoes for 10 days. For statistical analysis, analysis of variance (ANOVA) was conducted at a 5% significance level. All resulted data were expressed in mean ± SD.

3. Results and Discussions

3.1. Simulated Vibration Analysis

The accelerometers placed in the three positions of the plastic container recorded thousands of vibration signals. Histogram analysis was applied for all time-domain vibration signals to obtain the peaks number of accelerations per accelerometer (Table 1). The middle position recorded the maximum number of peaks (1664 peaks) at 2.5 Hz for 120 min in the acceleration interval of 0.0275 to 0.0280 m/s^2 with an acceleration occurrence reached 22.75%. This was followed by the bottom position of the container which generated 1248 peaks in the acceleration interval of 0.0053 to 0.0055 m/s^2. The acceleration interval of 0.0151 to 0.0156 m/s^2 of the top position recorded 896 peaks during the simulated transport experiment. The vibration recorded from each position of the tomato plastic container can indicate that tomato fruits can encounter several damages from each side of the packaging unit during transportation.

3.2. Physiological Weight Loss (%)

Figure 2 shows the weight loss (%) of both tomato groups stored at different storage conditions (10 and 22 °C) during the 10 days of storage. Tomato fruit weight loss was varied significantly ($p < 0.05$) between vibrated and control groups. Also, tomato weight loss was statistically influenced ($p < 0.05$) by storage condition and storage duration. Vibrated tomato fruits stored at ambient temperature (22 °C) had about 4.21% weight loss at the end of storage compared to the control tomato group that had 3.38% of weight loss at the same storage condition. The lowest tomato weight loss was recorded on the control group stored at 10 °C with 1.02% on day 10 of storage. While the vibrated tomatoes stored at 10 °C recorded a 1.39% weight loss on the last day of the study. As reported by Jung et al. [11], vibration can accelerate the increment of both respiration and ethylene rates resulted in a higher reduction in moisture content of the produce, consequently increasing weight reduction as storage duration increased. As stated by Xu et al. [13], vibration can prompt the process of ripening which is highly caused by the promotion of respiration rate and ethylene production. During ripening, an increase in weight loss can be observed due to water movement (water evaporation) from the produce to the surrounding environment. Also, Munhuewyi [29] confirmed that the rate of respiration is one of the main factors that contribute to weight alterations in fresh produce due to the conversion of carbon (C) atoms to atmospheric carbon dioxide (CO_2).

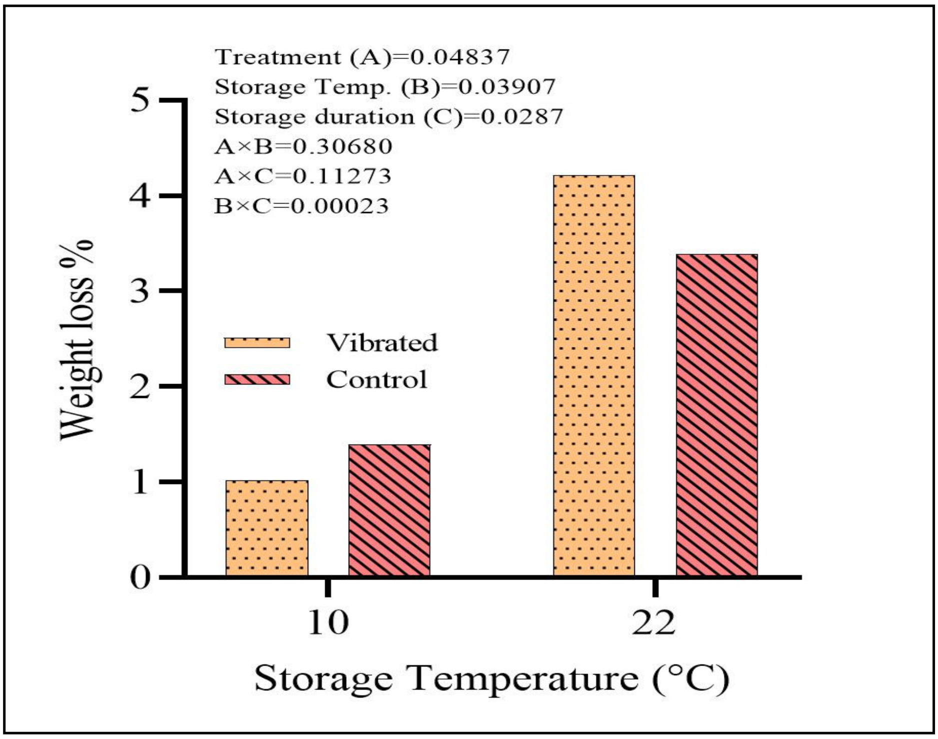

Figure 2. Weight loss (%) of vibrated and non-vibrated (Control) tomato fruits stored at 10 and 22 °C.

Table 1. Vibration accelerations data during simulated transport.

Top	Acceleration Interval ($\mathrm{m/s^2}$)	>0.0094	0.0099–0.0104	0.0104–0.0109	0.0109–0.0113	0.0113–0.0118	0.0118–0.0123	0.0123–0.0127	0.0127–0.0132	0.0132–0.0137	0.0137–0.0141	0.0141–0.0146	0.0146–0.0151	0.0151–0.0156	0.0156–0.0160	<0.0160
	Number of Peaks	42	145	203	239	737	595	674	790	374	358	816	839	896	549	57
	Acceleration distribution (%)	0.57	1.98	2.77	3.26	10.07	8.13	9.21	10.80	5.11	4.89	11.15	11.47	12.25	7.50	0.77
Middle	Acceleration Interval ($\mathrm{m/s^2}$)	>0.0247	0.252–0.0257	0.0257–0.0261	0.0261–0.0266	0.0266–0.0270	0.0270–0.0275	0.0275–0.0280	0.0280–0.0284	0.0284–0.0289	0.0289–0.0293	0.0293–0.0298	0.0298–0.0302	0.0302–0.0307	0.0307	-
	Number of peaks	78	68	57	139	775	1457	1664	1539	815	245	168	131	85	93	-
	Acceleration distribution (%)	1.06	0.92	0.77	1.90	10.29	19.92	22.75	21.04	11.14	3.34	2.29	1.79	1.16	1.27	-
Bottom	Acceleration Interval ($\mathrm{m/s^2}$)	>0.0036	0.0039–0.0042	0.0042–0.0044	0.0044–0.0047	0.0047–0.0050	0.0050–0.0053	0.0053–0.0055	0.0055–0.0058	0.0058–0.0061	0.0061–0.0063	0.0063–0.0066	0.0066–0.0069	0.0069–0.0071	<0.0071	-
	Number of peaks	137	339	616	1156	1213	874	1248	861	327	218	118	66	64	77	-
	Acceleration distribution (%)	1.87	4.63	8.42	15.80	16.58	11.94	17.06	11.77	4.47	2.98	1.61	0.90	0.78	1.05	-

Ghazal et al. [30] also recorded higher weight loss on tomato fruit stressed to vibration compared to the control tomato group due to higher respiration rate and mechanical damages caused by the simulated transport vibration. According to Endalew [31] and Al-Dairi et al. [6], storage at ambient temperature resulted in a greater transpiration rate that leads to wilting, shriveling, and weight reduction in tomatoes. Also, Al-Dairi et al. [2] recorded a low weight loss percentage (3.18%) on tomato fruit stored for 12 days at low temperature (10 °C) which attributed to water retention that occurred at this condition. Regarding weight loss kinetic, Table 2 demonstrates that the zero-order kinetic model gave the highest R^2 ($R^2 \geq 0.9483$) and the lowest values of X^2, and *RMSE* for weight loss of both control and vibrated tomato groups stored at both storage conditions (10 °C and 22 °C).

Table 2. The statistical values of zero-order and first-order models of control and vibrated tomato groups were stored at 10 °C and 22 °C for 10 days storage period.

Quality Parameter	Treatment	Temp.	Zero-Order Model				First-Order Model			
			k	R_2	X^2	*RMSE*	*k*	R^2	X^2	*RMSE*
Weight loss	C	10 °C	0.2111	0.9917	0.0012	0.0331	0.4149	0.9397	0.0325	0.1485
		22 °C	0.6627	0.9909	0.0790	0.1085	0.4357	0.9653	0.8850	0.1167
	V	10 °C	0.2733	0.9982	0.0270	0.0199	0.3537	0.9731	1.1982	0.5357
		22 °C	0.8416	0.9816	0.1660	0.1966	0.4868	0.9735	0.0765	0.1037
L*	C	10 °C	−1.0630	0.9483	0.0213	0.4239	−0.0215	0.9451	0.0001	0.0088
		22 °C	−2.2679	0.9593	0.0817	0.7982	−0.0502	0.9719	0.0003	0.0145
	V	10 °C	−1.9482	0.9720	0.0404	0.5643	−0.0418	0.9668	0.0002	0.0132
		22 °C	−2.6281	0.9604	0.1039	0.9109	−0.0599	0.9733	0.0004	0.0169
a*	C	10 °C	1.3427	0.9836	0.0187	0.2957	0.0481	0.9876	0.0001	0.0092
		22 °C	1.8395	0.9675	0.0683	0.5759	0.0622	0.9512	0.0010	0.0240
	V	10 °C	1.5191	0.9827	0.0246	0.3442	0.0532	0.9835	0.0002	0.0117
		22 °C	2.5830	0.9897	0.0447	0.4506	0.0823	0.9771	0.0008	0.2154
b*	C	10 °C	−1.0147	0.9539	0.0409	0.3811	−0.0430	0.9495	0.0007	0.0190
		22 °C	−1.5240	0.9486	0.1120	0.6059	−0.0786	0.9404	0.0023	0.0337
	V	10 °C	−1.2538	0.9528	0.0627	0.4764	−0.0620	0.9555	0.0010	0.0228
		22 °C	−1.9122	0.9804	0.0593	0.4616	−0.1041	0.9832	0.0011	0.0232
ΔE	C	10 °C	1.8760	0.8446	3.7311	1.3744	0.1539	0.8514	0.0207	0.0909
		22 °C	3.1374	0.9007	4.4746	1.7794	0.1761	0.9962	0.0004	0.0154
	V	10 °C	2.6917	0.9138	3.5762	1.4117	0.2040	0.9220	0.0165	0.0839
		22 °C	4.1489	0.9559	3.5630	1.5219	0.2294	0.9997	6.3×10^{-5}	0.0059
Chroma	C	10 °C	0.4437	0.7822	0.0275	0.3998	0.0126	0.7818	0.0002	0.0113
		22 °C	0.6751	0.8766	0.0307	0.4327	0.0187	0.8767	0.0002	0.0119
	V	10 °C	0.5043	0.8049	0.0308	0.4240	0.0142	0.8053	0.0002	0.0119
		22 °C	1.2289	0.9822	0.0129	0.2825	0.0328	0.9873	6.7×10^{-5}	0.0063
Hue	C	10 °C	−2.6247	0.9867	0.0426	0.5209	−0.0713	0.9809	0.0004	0.0170
		22 °C	−3.6755	0.9707	0.1914	1.0900	−0.1111	0.9784	0.0282	0.0013
	V	10 °C	−3.1014	0.9780	0.0947	0.7948	−0.0880	0.9797	0.0007	0.0217
		22 °C	−4.5943	0.9753	0.2494	1.2480	−0.1525	0.9875	0.0014	0.0293
CI	C	10 °C	0.1284	0.9669	0.0071	0.0405	0.0951	0.9799	0.0163	0.0232
		22 °C	0.2206	0.9671	0.0157	0.0695	0.1411	0.9759	0.0420	0.0378
	V	10 °C	0.1673	0.9708	0.0103	0.0496	0.1162	0.9793	0.0289	0.0288
		22 °C	0.3385	0.9724	0.0302	0.0974	0.1893	0.9872	0.0443	0.0367
Firmness	C	10 °C	−0.1401	0.7796	0.0301	0.1272	−0.0133	0.7610	0.0088	0.0414
		22 °C	−0.2481	0.9665	0.0124	0.0788	−0.0847	0.9572	0.0052	0.0306
	V	10 °C	−0.1822	0.9283	0.0147	0.0865	−0.0585	0.9404	0.0034	0.0251

C indicates the control group; V indicates the vibrated group.

3.3. Color

Figure 3 shows the significant ($p < 0.05$) interaction effect of treatments (vibration/control groups), storage conditions, and storage duration on tomato L* value. With storage time, a decreasing trend of the L* value of all vibrated and non-vibrated tomatoes at both storage temperatures for the 12 days storage was observed due to a reduction in brightness. However, the results of this study showed a higher L* value reduction (37.33) in tomato stressed to vibration compared to the control 39.83 group and stored at 22 °C. Besides, the non-vibrated tomatoes at 10 °C had a better (L*) color value (46.71) than tomatoes stressed to vibration after 10 days of storage. More changes of lightness were observed on tomatoes exposed to vibration due to the repeated vibration motions generated during simulated transport. Besides, the reduction of the color change of the L* value with storage time particularly at 22 °C is due to carotenoids synthesis which leads to tomato darkening [2]. Discoloration of fresh produce due to vibration results in enzymatic browning [32] like polyphenol oxidase (PPO) and peroxidase (POD) [33]. Lightness (L*) change kinetics on Table 2 shows that the zero-order model produced a high R^2 for both control ($R^2 = 0.9483$) and vibrated ($R^2 = 0.9720$) tomato groups stored at 10 °C. However, the first-order model was considered the most appropriate model to represent the L* value change for 10 days for both tomato groups stored at 22 °C. To validate the best model of the L* value of both tomato groups stored at both temperature conditions, the predicted values with the experimental data values were presented and plotted in Figure 4. The predicted values were in a very good correlation with the experimental values ($R^2 > 0.94$) where the predicted data banded around the straight line for all storage conditions and groups which validate the suitability of the selected.

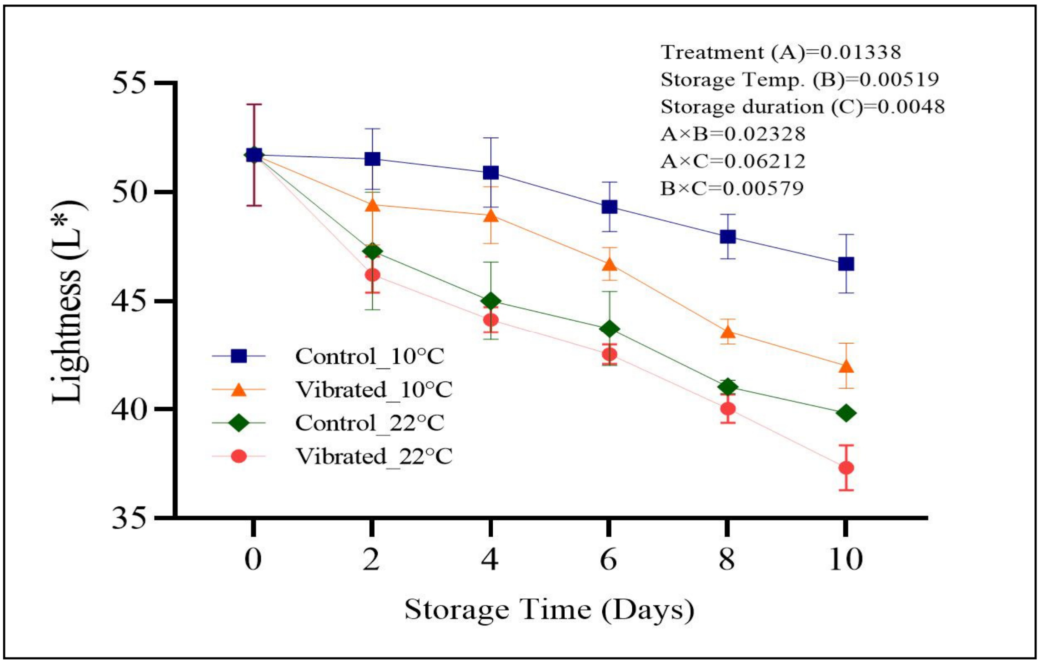

Figure 3. Lightness (L*) value of vibrated and non-vibrated (control) tomatoes stored at (A) 10 °C and (B) 22 °C for 10 days storage. Error bars represent the standard deviation (SD) of the mean values ± S.D of 15 readings per 3 replicates.

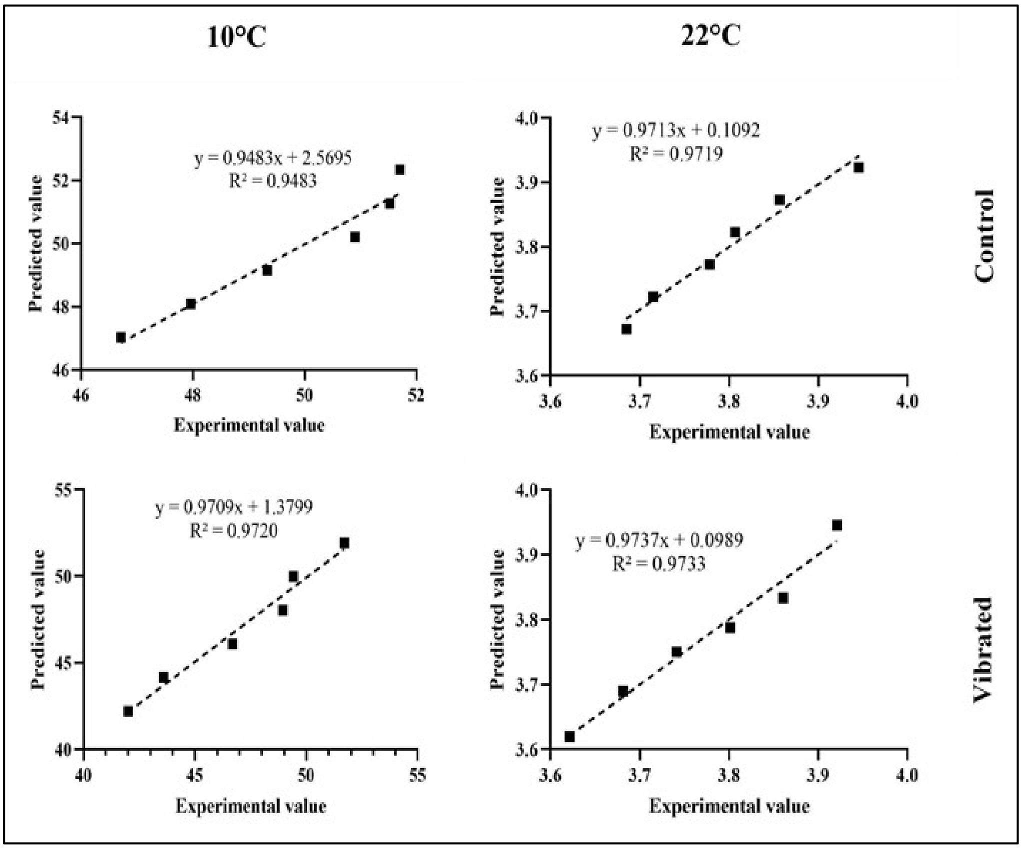

Figure 4. Predicted and experimental results of L* change kinetic of vibrated and non-vibrated (control) tomatoes stored at10 °C and 22 °C.

The redness (a*) was differed ($p < 0.05$) significantly between tomato groups (control and vibrated), storage condition, and storage duration. The redness increased dramatically as storage temperature and duration increased. Besides, vibration showed a higher a* value increment in tomatoes than those exposed to no-vibration. At the end of the 10 days storage period at 22 °C, the a* value percentage of increase in tomato stressed to simulated vibration was 54.14%, while it was 38.66% in tomatoes with no vibration (Figure 5). However, the control tomato group stored at 10 °C showed the lowest percentage of increase in both groups. The increment in redness observed on vibrated tomato samples could be attributed to the high percentage of acceleration occurrence generated from simulated transport resulted in increasing the ripening process of the samples. Besides, higher ethylene and respiration are responsible for vibrated tomato color changes. Also, Dagdelen and Aday [32] indicated an increase in the a* value of peach on the last day of storage due to the increase in respiration rate resulted from the mechanical vibration leading to fruit and color degradation. Wu and Wang [4] observed high red color development in tomatoes exposed to 60 min of simulated transport vibration. Furthermore, high temperature caused a rapid change in the redness value due to lycopene accumulation, rapid ripening, and chlorophyll degradation compared to low storage temperature with storage time [34]. The experimental data of a* value color kinetic of vibrated and control tomato groups stored at 10 °C was highly described by the first-order model. The zero-order kinetic model provided the highest (R^2) for the a* value of vibrated and control tomato groups stored at 22 °C Table 2. The good agreement reported between the predicted values and the experimental values can validate the appropriateness of the models in a* value color kinetic change (Figure 6).

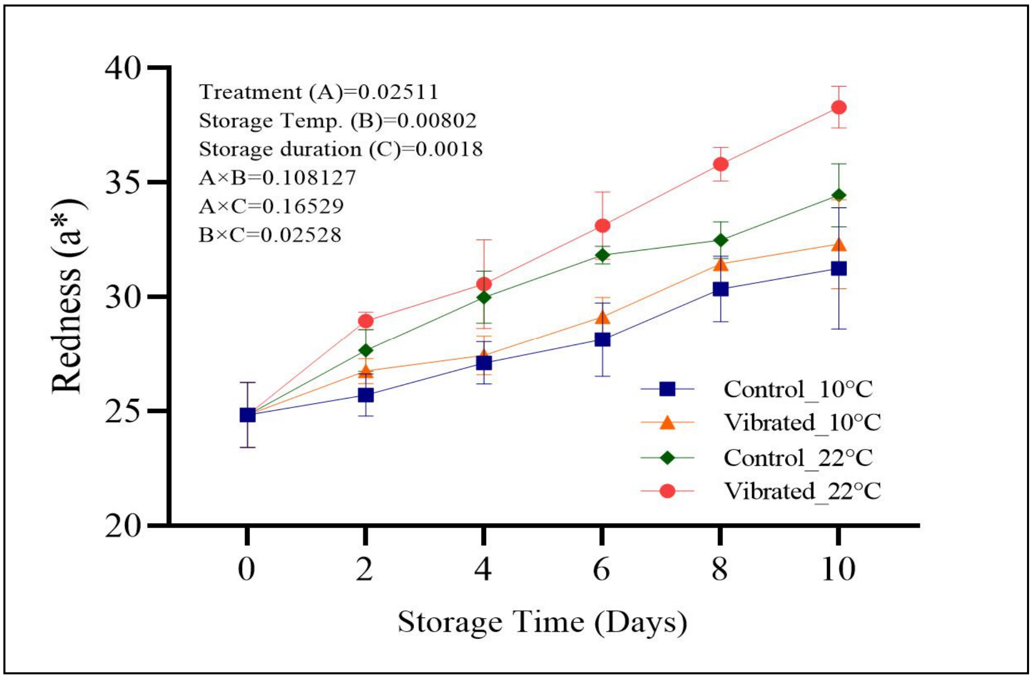

Figure 5. Redness (a*) value of vibrated and non-vibrated (control) tomatoes stored at 10 °C and 22 °C for 10 days storage. Error bars represent the standard deviation (SD) of the mean values ± S.D 15 readings per 3 replicates.

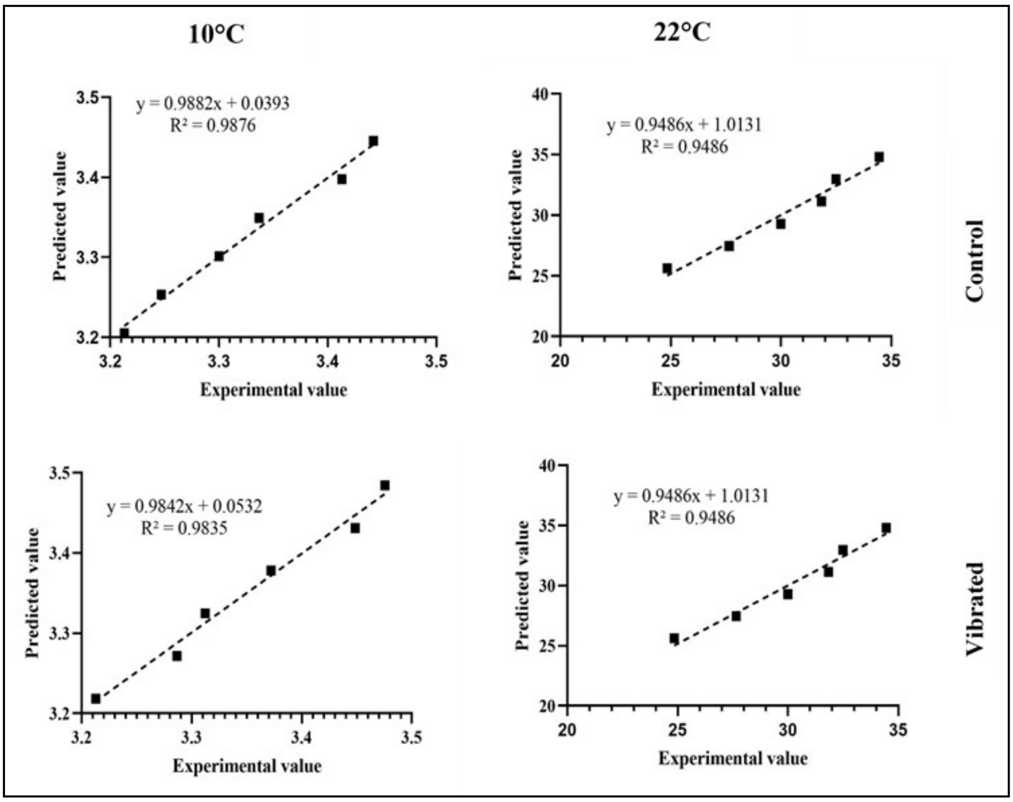

Figure 6. Predicted and experimental results of a* change kinetic of vibrated and non-vibrated (control) tomatoes stored at 10 °C and 22 °C.

The yellowness (b*) color from the two tomato groups decreased with storage temperature and storage period and a considerable b* value difference ($p < 0.05$) between the vibrated and control tomato groups was observed (Figure 7). On the last day of storage, vibrated tomato stored at 22 °C showed 18.35% more b* value reduction than the control group tomato stored at 10 °C that had the lowest reduction in the b* value among all tomato groups stored at both conditions. Endalew [31] recorded a reduction in the b* value of tomato at a higher temperature during storage due to red color increment. Table 2 shows that the b* value of control tomato groups stored at 10 °C and 22 °C was highly described by the zero-order model. However, the first-order kinetic model was adequately fitted with the b* value of vibrated tomato stored at 10 °C and 22 °C. Figure 8 indicated the correct selection of the kinetic models in the b* color kinetic change which was resulted from the good agreement and relation between the predicted and the experimental data values.

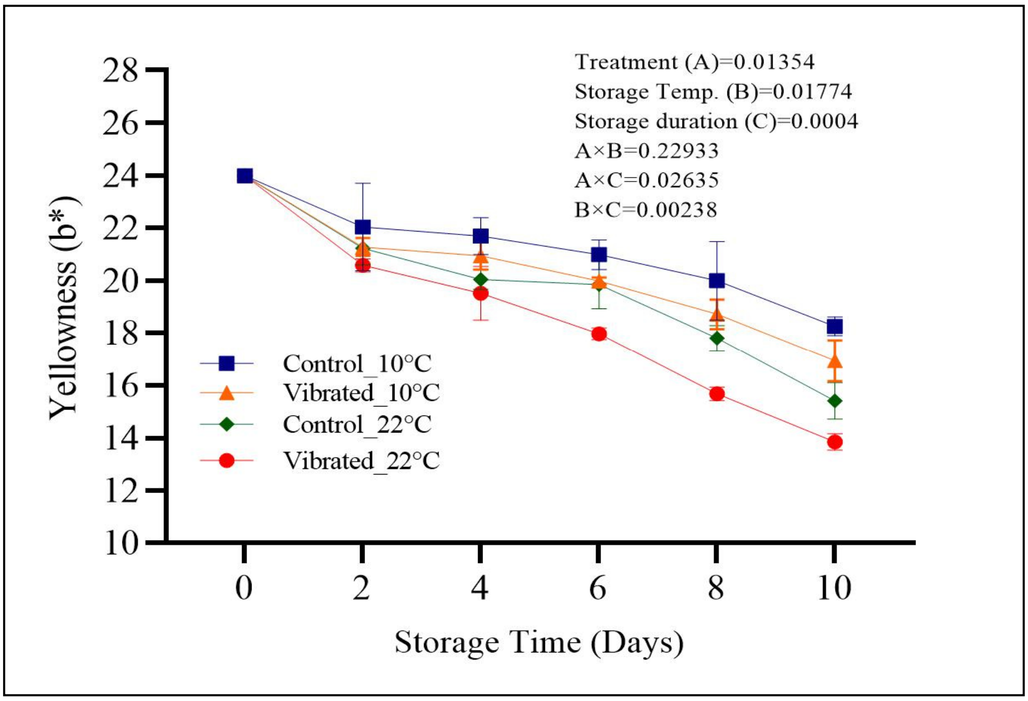

Figure 7. Yellowness (b*) value of vibrated and non-vibrated (control) tomatoes stored at 10 °C and 22 °C for 10 days storage. Error bars represent the standard deviation (SD) of the mean values ± S.D 15 readings per 3 replicates.

The color attributes of total color difference (ΔE), chroma, hue angle, and tomato color index were significantly ($p < 0.05$) varied with storage temperature condition and duration (Figure 9). Also, they were statistically ($p < 0.05$) differed between control and vibrated tomato groups, except with chroma, which had no pronounce ($p > 0.05$) significance between the tomato groups (vibrated and control). The total color difference value of tomato increased with storage time in all storage conditions and groups. The highest ΔE was observed in vibrated tomato group (22.87) followed by the control tomato group (17.86) stored at 22 °C (Figure 9A). On the last day of storage, the ΔE reached 15 and 11.16 on vibrated and control tomato groups stored at 10 °C, respectively (Figure 9A). The reduction in the hue° was higher in tomatoes exposed to vibration and stored at 22 °C with 54.99% than those exposed to no vibration at 10 °C (Figure 9B). Storage at 22 °C offered a faster reduction in hue angle caused due to the natural relation between chemical reactions and temperature that make tomato samples ripen rapidly and convert the green color of tomato to red [5]. During storage days, a fluctuation in chroma value was observed in tomato groups, particularly in those stored at 10 °C (Figure 9C). Despite this, the vibrated tomato group stored at 22 °C showed a dramatic increase in chroma for the 10 days storage period (Figure 9C). As tomato is exposed to vibration and stored at a higher temperature, more color index (CI) can be observed. The initial color index of tomato was 1.03 which later increased and reached 1.91 and 1.71 in vibrated and control tomato groups stored at

10 °C, respectively (Figure 9D). However, the increment was twice higher at 22 °C in the vibrated (2.29) and control (2.24) tomato groups (Figure 9D).

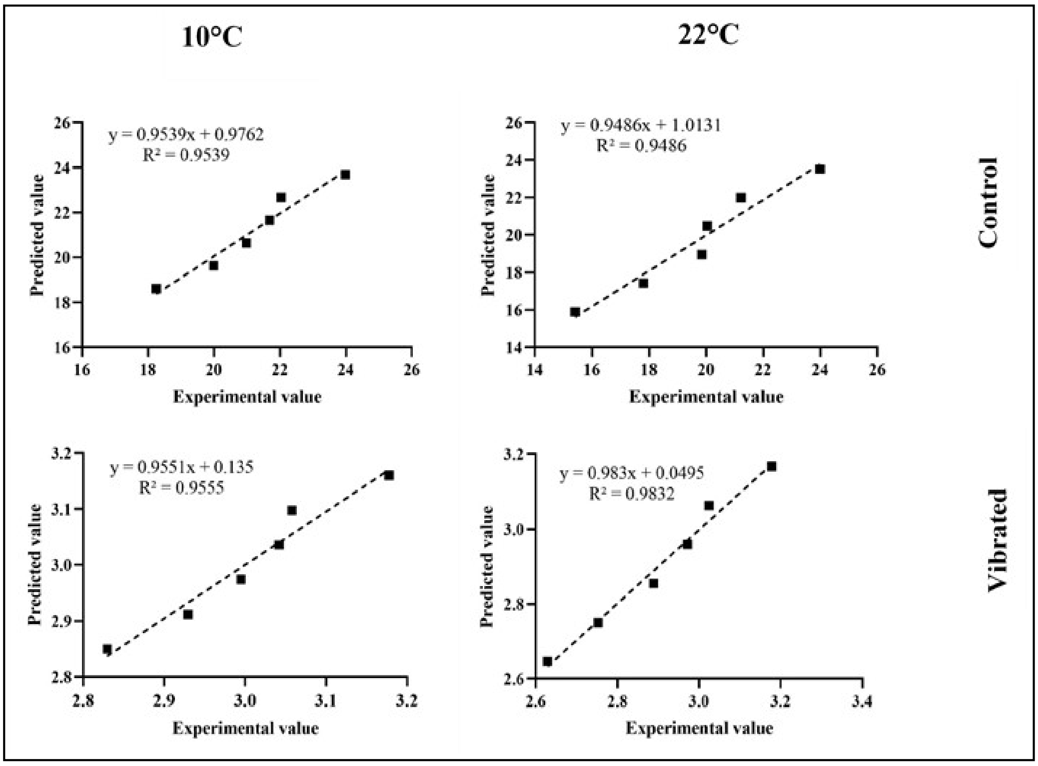

Figure 8. Predicted and experimental results of b* change kinetic of vibrated and non-vibrated (control) tomatoes stored at 10 °C and 22 °C.

Regarding model kinetics, Table 2 shows that the total color difference and tomato color index experimental data of all tomato groups stored at both storage conditions were better predicted by the first-order kinetic model. However, the zero-order model was found suitable to describe chroma and hue angle data of the control tomato group stored at 10 °C. To predict the kinetic changes in hue angle and chroma of vibrated tomato stored at both conditions and control tomato group at 22 °C, a zero-order model was selected (Table 2).

3.4. Firmness (N)

There was a significant difference ($p < 0.05$) in the firmness values between vibrated and control tomato groups. Besides, storage temperature conditions and storage duration were highly significant ($p < 0.05$) with firmness (Figure 10). The initial value of firmness in all tomato groups was 35.51 N. With storage time, the firmness reduced by 24% and 21.95% on vibrated and control tomato groups stored at 10 °C, respectively. When the vibrated and control tomatoes were stored at 22 °C, their firmness state became low with increasing storage duration. At the end of storage, tomatoes subjected to 2 h vibration and stored at 22 °C showed more reduction (44.82%) in firmness compared to those stressed no vibration (35.11%). As highlighted by Wei et al. [7], the vibration generated from simulated transport accelerated the ripening process, thus, reduced firmness with storage time. Dagdelen and Aday [32] reported that higher vibration during transportation can cause more damage to the produce cell wall, therefore, water loss and respiration increased due to structural degradation. In this study, firmness loss was observed in both control and vibrated tomato groups particularly at a storage temperature of 22 °C. This was attributed to the enzymatically controlled processes occurred at room temperature condition which is also link to other metabolic processes like respiration and transpiration as obtained by Cherono and Workneh [35]. Kabir et al. [21] and Al-Dairi et al. [36] found similar trends of firmness reduction at cold and ambient temperature conditions.

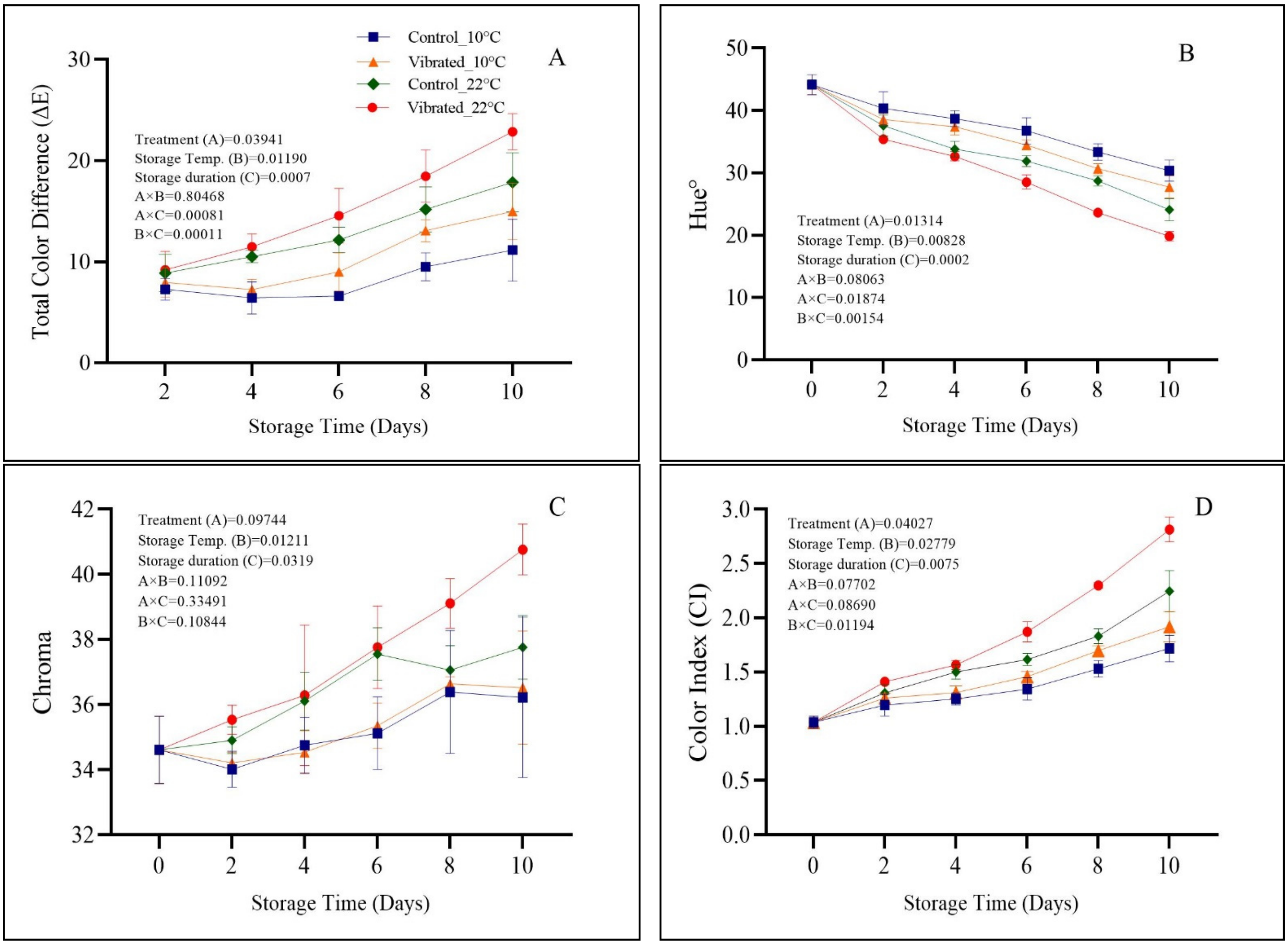

Figure 9. (**A**) Total color difference (ΔE), (**B**) hue angle (hue°), (**C**) chroma, and (**D**) tomato color index (CI) value of vibrated and non-vibrated (control) tomatoes stored at 10 °C and 22 °C for 10 days storage. Error bars represent the standard deviation (SD) of the mean values ± S.D 15 readings per 3 replicates.

The zero-order kinetic model was successfully fitted to experimental data of firmness reduction values of both vibrated to control tomato groups stored at 10 °C (Table 2). However, the first-order model gave the highest coefficient of determination (R^2) and low chi-square (X^2), and root mean square error (*RMSE*) of the firmness value of vibrated and non-vibrated tomatoes stored at room condition as shown in Table 2. Figure 11 illustrates the efficiency of the selected models. The straight line was banded by the predicted values of all tomato groups stored at both storage conditions. This can validate the suitability of the model chosen for this parameter.

3.5. Total Soluble Solids (°Brix)

The amount of total soluble solids (TSS) was increased significantly ($p < 0.05$) with storage time and storage conditions. Also, it was varied statistically ($p < 0.05$) between the tomato groups (Figure 12). A higher magnitude of TSS increment was observed in tomatoes exposed to two hours vibration (4.70 °Brix) than in the non-vibrated one (4.48 °Brix) where the increase accelerated by storage at 22 °C. The increase in TSS was also observed in vibrated and control tomatoes stored at 10 °C with 4.51 °Brix and 4.41 °Brix, respectively. Increasing TSS in tomatoes with simulated vibration stress compared to control tomatoes is owing to the rapid ripening of stressed tomatoes under these conditions. During storage, TSS increased more rapidly, suggesting a more ripening resulted in pectin substance degradation into more simple sugars e.g., Oligosaccharides [29]. More TSS was observed on samples subjected to vibration compared to the control samples by Dagdelen and Aday [32]. Similar results of significance on TSS between control and vibrated samples were also found on apples by Jung and Park [9]. A similar trend was observed by Kabir et al. [21] and Pathare and Al-Dairi [37], where increasing storage time can increase TSS contents. of fresh produce. Besides, Tigist et al. [34] recorded higher TSS content after the 32 days of storage at room temperature.

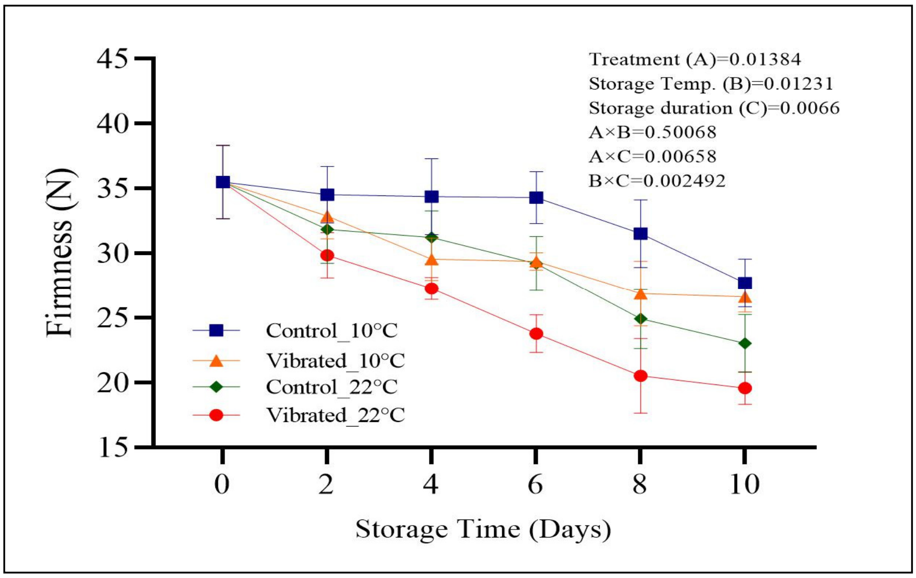

Figure 10. Firmness value (b*) of vibrated and non-vibrated (control) tomatoes stored at 10 °C and 22 °C for 10 days storage. Error bars represent the standard deviation (SD) of the mean values ± S.D of 6 readings per 3 replicates.

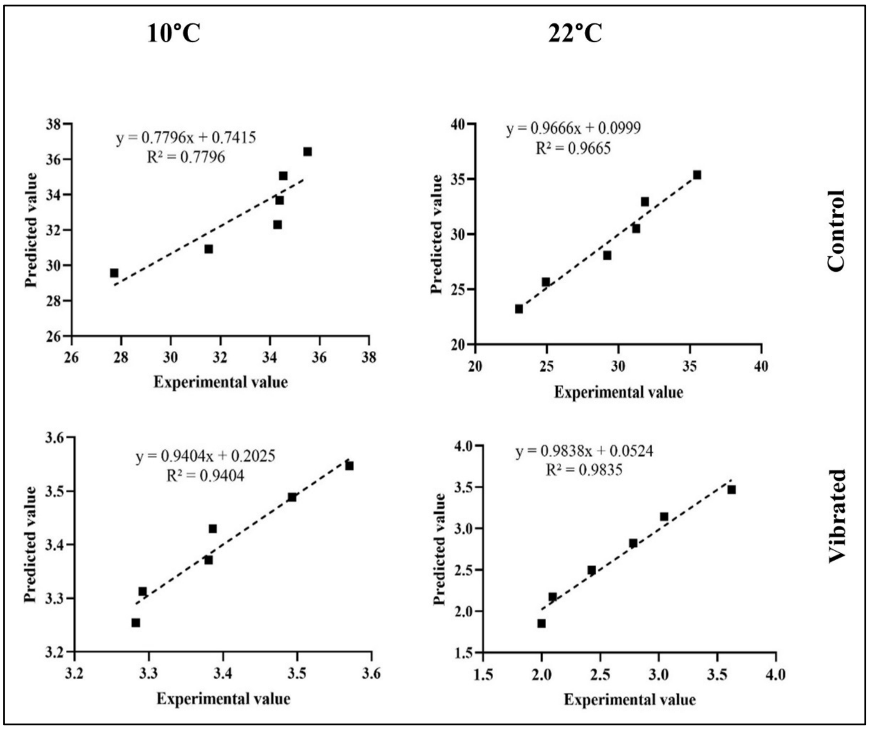

Figure 11. Predicted and experimental results of b* change kinetic of vibrated and non-vibrated (control) tomatoes stored at 10 °C and 22 °C.

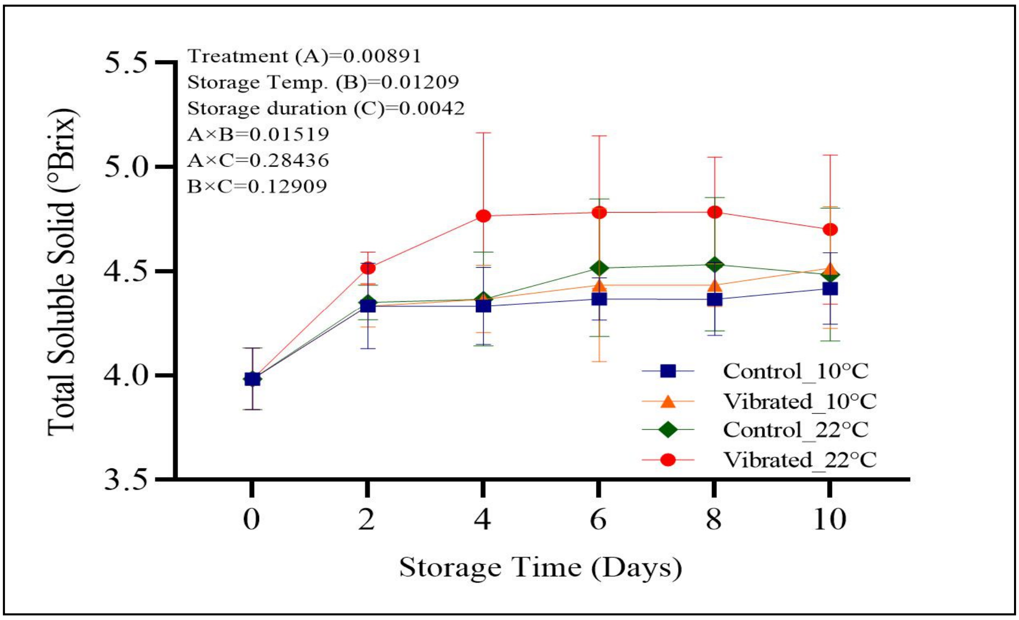

Figure 12. TSS value (Brix°) value of vibrated and non-vibrated (control) tomatoes stored at 10 °C and 22 °C for 10 days storage. Error bars represent the standard deviation(SD) of the mean values ± S.D 6 readings per 3 replicates.

3.6. Headspace Gases

Headspace O_2 and CO_2 concentration significantly ($p < 0.05$) declined over time at both storage temperatures. Headspace O_2 was not varied significantly ($p > 0.05$) between the vibrated and non-vibrated groups Table 3. The average O_2 concentration on day 2 was almost 16.85% and 16% in the control and vibrated stress group which reduced to reach 14.35% and 15.15% at 10 °C on day 8 respectively. More reduction was reported on O_2% in the control and vibrated tomato groups stored at 22 °C. On day 8, the vibrated tomato group showed a reduction in O_2 with 7.80% which later increased by 1% on day 10. Furthermore, more CO_2 increment was observed in tomatoes stored at 22 °C. On day 8, the CO_2 content reached 4.75 and 17.30% on the vibrated and control tomato groups respectively at 10 °C, while it was 4.55 and 17.75% respectively at 22 °C. The study suggested that both O_2 and CO_2 gases are correlated inversely during storage inside the gas collecting containers of tomatoes.

A significant increase was observed in ethylene (C_2H_4) at both storage conditions for 8 days storage period, which reduced on day 10 in all storage temperatures. There was no pronounce significance ($p < 0.05$) in C_2H_4 content between the vibrated group and the control tomato group. However, the vibrated tomatoes stored at room temperature recorded the highest content in C_2H_4 on day 8 with 3.25 ppm followed by the control tomatoes stored with 1.85 ppm compared to the initial value (1.45 and 1.25 ppm) respectively. Ethylene concentrations were 1.26 and 1.55 ppm in the control group and vibration stress group stored at 10 °C on day 8 respectively. All gases reached their equilibrium concentration on day 8 (Table 3). Low O_2 concentration activates anaerobic metabolites. The slow change in O_2 at 10 °C could result from the low rate of respiration at low-temperature storage conditions. Besides, the C_2H_4 production increased due to the continued ripening even after harvest. Therefore, C_2H_4 can accelerate the ripening of fresh produce [9].

3.7. Subjective Quality Analysis/Visual Observation of Mechanical Damage

The visual observation of the physiological damage and bruise incidence was mostly observed on the vibration stress tomato group at 22 °C (Figure 13) compared to the control group stored at both storage conditions. The damage on vibrated tomato at 22 °C reached 38.80%, while it was 5.50% on the control tomato group at the same temperature. No damage was observed on the control tomato stored in both conditions. Overall, the results of this study showed that vibration stress during simulated transport and storage at ambient accelerated the degradation of tomato with storage time.

Table 3. O_2%, CO_2% concentration, and C_2H_4 (ppm) production of control and vibrated tomato groups stored at 10 °C and 22 °C for 10 days storage period. Data are presented in mean values ± SD.

Headspace Gases	Treatment	Temp. °C	Days of Storage				
			2	4	6	8	10
O_2 (%)	C	10 °C	16.85 ± 0.21	16.35 ± 0.35	14.85 ± 0.07	14.35 ± 0.21	13.80 ± 0.42
		22 °C	12.20 ± 2.26	11.50 ± 2.82	10.80 ± 2.12	8.15 ± 0.91	7.85 ± 1.20
	V	10 °C	16.00 ± 1.41	16.20 ± 1.13	15.25 ± 0.21	15.15 ± 0.21	15.60 ± 0.14
		22 °C	11.80 ± 1.69	10.50 ± 0.70	9.55 ± 0.77	7.80 ± 0.14	8.00 ± 0.00
CO_2 (%)	C	10 °C	3.90 ± 0.00	4.25 ± 0.07	4.45 ± 0.07	4.75 ± 0.35	4.55 ± 0.07
		22 °C	9.15 ± 1.20	9.70 ± 1.83	11.00 ± 1.41	17.30 ± 0.84	15.30 ± 0.28
	V	10 °C	3.85 ± 0.07	3.95 ± 0.07	4.45 ± 0.07	4.55 ± 0.07	4.60 ± 0.00
		22 °C	9.30 ± 0.70	9.80 ± 1.55	11.10 ± 0.14	17.75 ± 1.34	16.15 ± 0.21
C_2H_4 (ppm)	C	10 °C	1.20 ± 0.00	1.20 ± 0.14	1.25 ± 0.07	1.26 ± 0.00	1.15 ± 0.07
		22 °C	1.25 ± 0.07	1.40 ± 0.00	1.65 ± 0.07	1.85 ± 0.07	1.40 ± 0.14
	V	10 °C	1.15 ± 0.21	1.30 ± 0.00	1.35 ± 0.07	1.55 ± 0.49	1.25 ± 0.14
		22 °C	1.45 ± 0.07	1.45 ± 0.07	1.75 ± 0.07	3.25 ± 1.90	1.86 ± 0.35

C indicates the control group; V indicates the vibrated group.

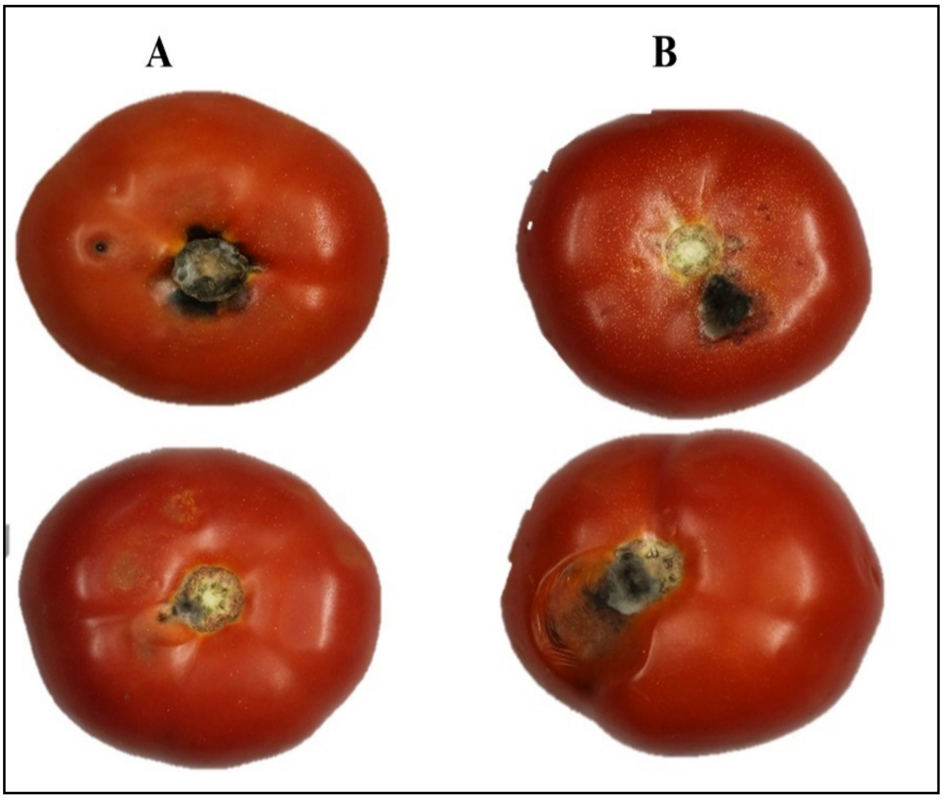

Figure 13. Physiological damages on the vibrated tomatoes stored at (**A**) 10 °C and (**B**) 22 °C after 10 days of storage.

4. Conclusions

The study investigated the effect of vibration stress generated from laboratory simulated transport and storage at two different storage conditions on the quality of tomatoes (weight loss %, color parameters, firmness, total soluble solids (TSS), and headspace gases) for 10 days. Based on the obtained results, weight loss %, firmness, lightness (L*), redness (a*), yellowness (b*), hue°, and total color changes (ΔE) were highly dependent on all studied factors (storage duration, vibration, and storage temperature conditions). A high reduction in weight, L*, b*, firmness, O_2 and hue angle, and increment in a*, TSS, color index (CI), C_2H_4 content, and CO_2 in the vibrated tomato fruits at room temperature 22 °C. Storage at low temperature (10 °C) reduced the quality changes occurrence of both control and vibrated tomato groups. The experimental data of weight loss, color, and firmness values were highly fitted to zero and first-order kinetic models. It was also found that the first-order kinetic model was the best model applied to represent the quality changes kinetic of both tomato groups at 10 and 22 °C. Proper technologies during transportation and storage are required to minimize the quality changes and degradation of tomatoes in the harvesting-consumption system.

Author Contributions: Conceptualization, P.B.P.; formal analysis, M.A.-D.; data curation, M.A.-D.; writing—original draft preparation, M.A.-D.; writing—review and editing, P.B.P.; supervision, P.B.P.; funding acquisition, P.B.P. All authors have read and agreed to the published version of the manuscript.

Funding: The research leading to these results received funding from the Research Council (TRC) of the Sultanate of Oman under Block Funding Program (TRC Block Funding Agreement No. RC/GRG-AGR/SWAE/19/01). We would like to thank Sultan Qaboos University for their financial support under the project code: IG/AGR/SWAE/19/03.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is contained within the article.

Acknowledgments: Help in conducting headspace gas experiment given by Adil Al-Mahdouri is thankfully acknowledged.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Famuyini, J.; Sedara, A. Effect of Maturity Stage on Quality and Shelf Life of Tomato (Lycopersicon Esculentum Mill) Using Refrigerator Storage System. *Eurasian J. Agric. Res.* **2020**, *4*, 23–44.
2. Al-Dairi, M.; Pathare, P.B.; Al-Mahdouri, A. Effect of Storage Conditions on Postharvest Quality of Tomatoes: A Case Study at Market-Level. *J. Agric. Mar. Sci.* **2021**, *26*, 13–20.
3. Chero, M.J.S.; Zamora, W.R.M.; Chero, J.A.S.; Villarreyes, S.S.C. Application of the Computer Vision System to the Measurement of the CIE L* a* B* Color Parameters of Fruits. In *Advances in Artificial Intelligence, Software and Systems Engineering*; Ahram, T., Ed.; Advance Intelligent Systems and Computing; Springer: Cham, Switzerland, 2020; Volume 1213.
4. Wu, G.; Wang, C. Investigating the Effects of Simulated Transport Vibration on Tomato Tissue Damage Based on Vis/Nir Spectroscopy. *Postharvest Biol. Technol.* **2014**, *98*, 41–47. [CrossRef]
5. Cherono, K.; Sibomana, M.; Workneh, T.S. Effect of Infield Handling Conditions and Time to Pre-Cooling on the Shelf-Life and Quality of Tomatoes. *Braz. J. Food Technol.* **2018**, *21*, 1–12. [CrossRef]
6. Al-Dairi, M.; Pathare, P.B.; Al-Yahyai, R. Effect of Postharvest Transport and Storage on Color and Firmness Quality of Tomato. *Horticulturae* **2021**, *7*, 163. [CrossRef]
7. Wei, X.; Xie, D.; Mao, L.; Xu, C.; Luo, Z.; Xia, M.; Zhao, X.; Han, X.; Lu, W. Excess Water Loss Induced by Simulated Transport Vibration in Postharvest Kiwifruit. *Sci. Hort.* **2019**, *250*, 113–120. [CrossRef]
8. Alfatni, M.S.M.; Shariff, A.R.M.; Abdullah, M.Z.; Marhaban, M.H.B.; Saaed, O.M.B. The Application of Internal Grading System Technologies for Agricultural Products–Review. *J. Food Eng.* **2013**, *116*, 703–725. [CrossRef]
9. Jung, H.; Park, J.-G. Effects of Vibration Stress on the Quality of Packaged Apples During Simulated Transport. *J. Biosyst. Eng.* **2012**, *37*, 44–50. [CrossRef]
10. Walkowiak-Tomczak, D.; Idaszewska, N.; Łysiak, G.P.; Bieńczak, K. The Effect of Mechanical Vibration During Transport under Model Conditions on the Shelf-Life, Quality and Physico-Chemical Parameters of Four Apple Cultivars. *Agronomy* **2021**, *11*, 81. [CrossRef]
11. Jung, H.M.; Lee, S.; Lee, W.-H.; Cho, B.-K.; Lee, S.H. Effect of Vibration Stress on Quality of Packaged Grapes during Transportation. *Eng. Agric. Environ. Food* **2018**, *11*, 79–83. [CrossRef]
12. Tao, F.; Chen, W.; Jia, Z. Effect of Simulated Transport Vibration on the Quality of Shiitake Mushroom (*Lentinus edodes*) during Storage. *Food Sci. Nutr.* **2020**, *9*, 1152–1159.

13. Xu, F.; Liu, S.; Liu, Y.; Wang, S. Effect of Mechanical Vibration on Postharvest Quality and Volatile Compounds of Blueberry Fruit. *Food Chem.* **2021**, *349*, 129216. [CrossRef] [PubMed]
14. Al-Dairi, M.; Pathare, P.B.; Al-Yahyai, R. Chemical and Nutritional Quality Changes of Tomato during Postharvest Transportation and Storage. *J. Saudi Soci.Agric. Sci.* **2021**, *20*, 401–408.
15. Xu, D.; Zuo, J.; Li, P.; Yan, Z.; Gao, L.; Wang, Q.; Jiang, A. Effect of Methyl Jasmonate on the Quality of Harvested Broccoli after Simulated Transport. *Food Chem.* **2020**, *319*, 126561. [CrossRef] [PubMed]
16. Chaiwong, S.; Bishop, C.F. Effect of Vibration Damage on the Storage Quality Of'elsanta'strawberry. *Aust. J. Crop Sci.* **2015**, *9*, 859–864.
17. Walkowiak-Tomczak, D.; Idaszewska, N.; Bieńczak, K.; Kómoch, W. The Effect of Mechanical Actions Occurring during Transport on Physicochemical Changes in Agaricus bisporus Mushrooms. *Sustainability* **2020**, *12*, 4993. [CrossRef]
18. Pathare, P.B.; Al-Dairi, M. Bruise Damage and Quality Changes in Impact-Bruised, Stored Tomatoes. *Horticulturae* **2021**, *7*, 113. [CrossRef]
19. Pathare, P.B.; Al-Dairi, M.; Al-Mahdouri, A. Bruise Damage Susceptibility and Fruit Quality Assessment of Pear. *Open Agric. J.* **2021**, *15*, 82–90. [CrossRef]
20. Arah, I.K.; Kumah, E.K.; Anku, E.K.; Amaglo, H. An Overview of Post-Harvest Losses in Tomato Production in Africa: Causes and Possible Prevention Strategies. *J. Bio. Agric. Healthc.* **2015**, *5*, 78–88.
21. Kabir, S.N.; Rasool, K.; Lee, W.-H.; Cho, S.-I.; Chung, S.-O. Influence of Delayed Cooling on the Quality of Tomatoes (*Solanum lycopersicum* L.) Stored in a Controlled Chamber. *AIMS Agric. Food.* **2020**, *5*, 272. [CrossRef]
22. Remini, H.; Mertz, C.; Belbahi, A.; Achir, N.; Dornier, M.; Madani, K. Degradation Kinetic Modelling of Ascorbic Acid and Colour Intensity in Pasteurised Blood Orange Juice During Storage. *Food Chem.* **2015**, *173*, 665–673. [CrossRef]
23. Al-Dairi, M.; Pathare, P.B.; Al-Yahyai, R. Quality Changes Kinetic of Tomato During Postharvest Transportation and Storage. *J. Food Proc. Eng.* **2021**, *44*, e13808. [CrossRef]
24. Al-Dairi, M.; Pathare, P.B. Kinetic Modeling of Quality Changes of Tomato During Storage. *Agric. Eng. Int. CIGR J.* **2021**, *23*, 183–193.
25. Zhang, W.; Luo, Z.; Wang, A.; Gu, X.; Lv, Z. Kinetic Models Applied to Quality Change and Shelf Life Prediction of Kiwifruits. *LWT* **2021**, *138*, 110610. [CrossRef]
26. Pathare, P.B.; Opara, U.L.; Al-Said, F.A. Colour Measurement and Analysis in Fresh and Processed Foods: A Review. *Food Bioproc Technol.* **2013**, *6*, 36–60. [CrossRef]
27. Chayjan, R.A.; Alaei, B. New Model for Colour Kinetics of Plum under Infrared Vacuum Condition and Microwave Drying. *Acta Sci. Pol. Technol. Aliment.* **2016**, *15*, 131–144. [CrossRef]
28. Pinheiro, J.; Alegria, C.; Abreu, M.; Gonçalves, E.M.; Silva, C.L. Kinetics of Changes in the Physical Quality Parameters of Fresh Tomato Fruits (*Solanum lycopersicum*, Cv.'Zinac') During Storage. *J. Food Eng.* **2013**, *114*, 338–345. [CrossRef]
29. Munhuewyi, K. Postharvest Losses and Changes in Quality of Vegetables from Retail to Consumer: A Case Study of Tomato, Cabbage and Carrot. Master's Thesis, Stellenbosch University, Stellenbosch, WC, South Africa, 2012.
30. Ghazal, A.; El-Masry, G.; El-Sheikh, I.; Radwan, S. Estimation of Some Postharvest Losses in Tomato During Simulated Transport Operation. *Misr J. Agric. Eng.* **2017**, *34*, 291–316. [CrossRef]
31. Endalew, E. Postharvest Loss Assessment of Tomato (*Lycopersicon esculentum* Mill) (Galilea Cultivar) Along the Postharvest Supply Chain, Northwest Ethiopia. Master's Thesis, Bahir Dar University, Amhara, Ethiopia, 2020.
32. Dagdelen, C.; Aday, M.S. The Effect of Simulated Vibration Frequency on the Physico-Mechanical and Physicochemical Properties of Peach During Transportation. *LWT* **2021**, *137*, 110497. [CrossRef]
33. Sun, L.; Liu, S.; Fan, Z.; Li, Y.; Wang, J.; Zhong, Y.; Zhang, Q.; Duan, X. The Impact of Storage Temperature on Fruit Quality and Chilling Injury of 'Okubao'peaches. *Int. J. Food Biosci.* **2018**, *1*, 12–18.
34. Tigist, M.; Workneh, T.S.; Woldetsadik, K. Effects of Variety on the Quality of Tomato Stored under Ambient Conditions. *J. Sci. Technol.* **2013**, *50*, 477–486. [CrossRef] [PubMed]
35. Cherono, K.; Workneh, T. The Efficacy of Postharvest Biocontrol Treatments in Controlling Spoilage of Tomato Fruit in South African Commercial Supply Chains. *J. Eng. Agric. Environ.* **2020**, *5*, 19–25. [CrossRef]
36. Al-Dairi, M.; Pathare, P.B.; Al-Mahdouri, A. Impact of vibration on the quality of tomato produced by stimulated transport. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, UK; London, UK, 2021; p. 012101.
37. Pathare, P.B.; Al-Dairi, M. Bruise Susceptibility and Impact on Quality Parameters of Pears During Storage. *Front. Sustain. Food Syst.* **2021**, *5*, 658132. [CrossRef]