Impact of vibration on the quality of tomato produced by stimulated transport

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Abstract. This paper aims to investigate the potential effect of vibration stress during stimulated transport and to evaluate the effect of storage’s temperature and duration on weight loss, color changes, firmness, and total soluble solid of tomatoes. Vibration shaker was used to simulate the transport vibration and accelerometer was fixed on different locations inside the container. Tomatoes were divided into 2 groups where the first one stressed for 2 hrs at the frequency of 2.5Hz and the other was not vibrated as a control. All tomatoes were stored at 10 and 22°C for 10 days. Weight loss, color changes, and firmness total soluble solids (TSS) were measured. RGB acquisition system was used to measure color changes on tomato and then analysed by ImageJ software. Lightness, redness, yellowness, purity, saturation, color change and some color indices of tomato were calculated. Analysis of variance (ANOVA) was used to analyse all obtained data. This research proves that the color, weight, firmness and total soluble solids of tomato altered by the vibration stresses and storage’s temperature and duration. Advanced methods and technologies need to be studied regarding temperature storage managements and transportation facilities to reduce the rapid changes of the quality.

1. Introduction

Transportation is very important to distribute fresh produce after being harvested [1]. Unlike other processes in postharvest fresh produce supply chain, transportation is considered as a delicate operation that can negatively affect fruits and vegetables [2]. High postharvest losses can be occurred if there is no appropriate transportation facilities to transport fruits and vegetables to the market [3]. There are many factors leading to postharvest losses during transport including the use of non-refrigerator trucks, bad roads [3], fresh produce properties [4] and the surrounded environment [5].

However, vibration produced by vehicles during transportation of fresh produce is one of the major issues that can cause different internal and external damages to fruits and vegetables [1], particularly soft fresh produce [6]. The vibration generated due to transportation is influenced by distance, road roughness, packaging units, speed and some other characteristics of the truck [4].

Different chemical and physical characteristics changes of fresh produce occurred by vibration have been investigated. Different studies have been carried out to evaluate the mechanical damages to different fruits and vegetables during transport like apple [4, 7], kiwifruit [6], pears [8, 9], strawberry [10] and tomato [11, 12]. The damage caused by vibration during transportation can cause high deterioration to fresh produce within short time. It can directly affect ripening, water loss [13], firmness, sugar content [7] and color [14].
Another factor to consider is storage temperature which is another operational concern in postharvest supply chain. Inappropriate storage temperature can increase the losses of any stored fresh produce [15]. Therefore, effecting the damage rate of the produce quality due to the continues changes in respiration, transpiration and ethylene production [16].

Tomato is one of the highly consumed fresh produce throughout the world which considers as a significant source of vitamins, dietary antioxidants and different beneficial minerals [11]. Since tomato is known as a typical example of tender fresh produce [12], excessive vibration during transportation can greatly affect tissues damage and decrease its external and internal quality characteristics. Therefore, the contribution of vibration generated form simulated transport as well as storage temperature in tomato quality attributes like weight, color, firmness and total soluble solids (TSS) were investigated in the current study for 10 days storage period.

2. Methods

2.1. Sample preparation, vibration treatment and storage treatment

Tomatoes of 'Roma' variety was purchased from the market (23°36'01.5"N latitudes and 58°12'18.9"E longitudes) and delivered to Postharvest Laboratory, Sultan Qaboos University (23°35'25.1"N latitudes and 58°10'07.9"E longitudes), Sultanate of Oman. Tomatoes which had similar weight (0.177±0.02 kg), size, color, and free from misshapenness and blemishes were selected, cleaned, and divided into two groups. The first one stressed to vibration for a specified duration of 2 hrs to simulate the distance of 156 km. The other group was experienced no vibration stress and set as control.

For vibration test, a mechanical vibration shaker (Model: SM25, Edmund Bühler GmbH, Germany) was used at frequency of 2.5Hz by sitting the shaker speed at 150 rev/min for a duration of 120 minutes. Tomato samples which were stacked inside the Recycle Plastic Container (RPC) (365x255x155mm) were placed in the top of the shaker. In order to record the data related to vibration, 3 vibration/accleration data loggers (Model: OM-VIB101, Spectris plc, USA) were used and fixed in the bottom, middle and top positions of the tomato container. Vertical direction of vibration acceleration was measured [17]. The sensors recorded data every 1 sec of simulated transport. The signals (in thousands) generated from each accelerometer from each position of tomato container during simulated transport were later converted to personal computer to be analyzed on shock application (Vibration data logger v2.3). To evaluate the number of acceleration vibration generated (time-domain) for each accelerometer during simulated transport, vibration analysis was performed. Therefore, a histogram was applied to detect the number of peaks obtained from each accelerometer (each position) during simulated transport experiment.

After vibration treatment, tomato samples were divided equally into two group where the first one stored at 10±0.5°C (95±1% RH) and the other at 22±1°C (65±5% RH). Tomatoes without vibration stress experienced same storage treatment. To study the effect of vibration and storage on tomato quality parameters, both vibrated and control tomato groups were subjected to different quality assessment like weight loss, color, firmness, and total soluble solids at 2 days intervals for 10 days storage period. Three replicates of tomato samples were analyzed before vibration and storage treatments for 0 day assessment.

2.2. Quality evaluation

2.2.1. Weight loss %. Weight loss was measured for every 2 days by measuring whole tomato groups using an electronic balance (Model: GX.4000, Japan). The results were expressed as a percentage loss of the weight recorded at the initial day of the experiment.

2.2.2. Color measurements. The external color for 3 replicates of vibrated and control group was measured at 2 days interval using RGB (Red, Green, Blue) image acquisition system (Figure 1).
This system was setup as recorded by [18] which includes different components like RGB color camera (Model: EOS FF0D, Canon Inc., Japan), two fluorescent lights, an image capture board, an image chamber, personal computer, and computer software. The tomato sample was placed in a white background (stage) where 5 reading were taken per each tomato sample. For this study, RGB image was captured with a resolution of 5184 × 3456 pixel and stored on the personal computer in JPG format. For image analysis, image processing public domain ImageJ software (v. 1.53, National Institute of Health, MD, USA) was performed. RGB values were estimated using histogram tool available in ImageJ. Later, RGB values were converted to CIELab color space which was selected as it is the most frequently used in quality studies for fresh produce Figure 1. Next, total color difference (ΔE), chroma, hue°, and color index (CI) were calculated as [19]:

\[
\text{Total color difference (ΔE*)} = \sqrt{\Delta a^* + \Delta b^* + \Delta L^*} \\
\text{Chroma} = \sqrt{\Delta a^* + \Delta b^*} \\
\text{Hue°} = \tan^{-1}\left(\frac{\Delta b^*}{\Delta a^*}\right) \\
\text{Color index (CI)} = \frac{a^*}{b^*}
\]

![Figure 1. A schematic diagram of RGB image acquisition system and image processing](image)

2.2.3. Firmness. Two positions of each tomato sample were selected to measure the changes in tomato firmness using digital fruit firmness tester (Model: FHP-803, L.L.C., USA) as the unit of kgf.

2.2.4. Total soluble solids (TSS). A digital refractometer (Model: PR-32 α, ATAGO Co., Ltd, Japan) was used to measure total soluble solids (TSS) of both control and vibrated groups which was expressed in °Brix.

2.3. Statistical analysis

In this research, SPSS 20.0 (International Business Machine Corp., USA) was performed to study the effect of experimental variables i.e. vibration and storage condition on the quality characteristics of tomato such as weight loss, firmness, color, and total soluble solids (TSS) by applying two factorial
balanced analysis of variance (ANOVA) where the mean value was considered at 5% significance level. In addition, mean and standard deviation were calculated for all obtained data.

3. Results and discussions

3.1. Vibration analysis of simulated transport

Thousands of signals have been recorded from each accelerometer that was fixed in each position of tomato container. Histogram of all generated vibration data were utilized to quantify the number of peaks of acceleration for each position per second (Figure 2) by dividing all time-domain signals into different intervals. Figure 2 shows that the maximum number of acceleration vibration peak was found in the acceleration interval of 2.75-2.80 g with 1664 peaks per second of middle position. It was followed by the acceleration interval of 0.53-0.55 g and 1.51-1.56 g with 1248 and 896 peaks per second of bottom and top positions. The percentage of acceleration occurrence of 2.75-2.80 g acceleration interval was 22.75%. Overall, the results indicated that vibration occurred in different positions of tomato container. It means tomato samples could face damage from each place inside the container.

3.2. Tomato quality analysis

3.2.1. Weight loss %. The weight of tomato is a significant quality attribute because the price of any fresh produce is decided by its weight. Weight loss (%) comparison between control tomato group and vibrated tomato group stored at 10°C and 22°C for 10 days storage period is shown in (Figure 3). As expected, there is a significant difference (p<0.05) weight loss percentage between the two groups (vibration and control) at all storage conditions. Tomato samples exposed to vibration and stored at 22°C experienced significantly higher weight reduction of 4.21% while tomato samples without vibration stresses showed a weight loss of 3.38%. Vibrated tomato stored at 10°C showed 1.39% losses on weight compared to the control tomato group at same storage temperature condition which
found to be the lowest (1.02%). The observation on vibrated tomato show that storage at ambient temperature attributes to the increase of respiration and ethylene production rate which caused by the exposure of stress in tomato during stimulated transport that lead to the accelerate moisture contact rate reduction in the produce [13, 20]. Therefore, more weight loss was experienced at 22°C as the duration of storage lasted.

![Figure 3](image-url)

**Figure 3.** Weight loss of vibrated and control tomato groups stored at 10°C and 22°C for a period of 10 days

3.2.2. **Color.** Among the appearance attributes, color is one of the characteristics that mostly used to categorize tomato’s quality, freshness, and attractiveness. Color parameters were significantly \((p<0.05)\) affected by treatments on the two groups (vibrated and control), storage temperature (10 and 22°C), and storage duration. However, Chroma was not affected by vibration treatment \((p>0.05)\), but affected by storage temperature and storage period \((p<0.05)\). Among the color measurements, lightness \((L^*)\) was highly reduced during storage at 22°C from 51.70 to 37.33 and 39.83 on vibrated tomato groups and control tomato group respectively. Significant but less reduction was found in vibrated (42) and control (46.71) tomato groups at 10°C (Figure 4). The rapid increase and alteration of lightness on vibrated tomato could be attributed to multiple vibration stresses. Regarding temperature, more change in tomato lightness was reported at room temperature. The darkening on tomato is altered by the synthesis of carotenoids [21].

![Figure 4](image-url)

**Figure 4.** \(L^*\) value of vibrated and control tomato groups stored at 10°C and 22°C for a period of 10 days
At the beginning, the average value of redness in tomato samples was 24.83. The redness of tomato color ($a^*$) was greater in vibrated tomato group (38.29) compared to control tomato group (34.45) stored at room temperature condition for 10 days storage. It was followed by vibrated tomato and control tomato at 10°C with 32.07 and 31.78 respectively (Figure 5). As observed by [3], storage at room condition can provide an ideal environment for tomato which increase of the ripening state. The increasing of tomatoes ripening state in room condition resulted in the higher increasing of redness compared to tomato at cold temperature storage. Ethylene biosynthesis [22], lycopene synthesis and chlorophyll degradation are other reasons for redness increasing in tomato at 22°C storage temperature [23]. Other than that, vibration has been known to increase the redness in the tomato which is also stated by Wu and Wang [11] that experienced great increase in red color in tomato when stressed by high vibration for 60 minutes during stimulated transport.

In contrast, tomato had a rapid decline on $b^*$ in both vibrated and control group at both storage temperature conditions for 10 days (Figure 6). Tomato group subjected to 2 hrs vibration and stored at room temperature showed more reduction on $b^*$ value from 23.98 on the first day of storage to 13.85 on the last day of storage period. Less reduction on $b^*$ value was shown on non-vibrated tomato group stored at 10°C from 23.98 to 18.25 on day 10.

Figure 5. $a^*$ value of vibrated and control tomato groups stored at 10°C and 22°C for a period of 10 days

Figure 6. $b^*$ value of vibrated and control tomato groups stored at 10°C and 22°C for a period of 10 days
Total Color difference (ΔE) increased significantly throughout the experiment at both groups and storage temperature (Figure 7). The greatest increase in total color differences were recorded in vibrated tomato group at room temperature (22.87). Lower increase in total color differences were shown in control tomato group at 10°C. As mentioned earlier, tomato color saturation (chroma) was not affected in both control and vibrated tomato, but it was affected by storage temperature and storage period (Figure 8). However, the trend of color purity of tomato (hue°) was different between both vibrated group and non-vibrated group at both storage temperature during storage period. The initial value hue° in tomato was 44.15° and reduced significantly to reach 24.11° and 19.87° on control and vibrated tomato group stored at 22°C, respectively. Storage at room temperature gradually reduced hue° during storage period, which is attributed to ripening process, color change from green to red, and the natural relationship between temperature and the rate of biochemical reaction [24]. Less reduction in hue° observed in tomato of vibrated (27.74°) and control (30.36°) groups stored at 10°C (Figure 9). The same trend was observed in tomato color index (CI). Red color development was strongly observed on tomato stressed to vibration which later stored at 22°C with 2.81 compared to the control group with 2.24 in the last day of storage. Storage at 10°C showed less increase in color index in both groups with 1.91 (vibrated) and 1.71 (control) on day 10 of storage (Figure 10).

![Figure 7](image7.png)

**Figure 7.** Total color difference of vibrated and control tomato groups stored at 10°C and 22°C for a period of 10 days

![Figure 8](image8.png)

**Figure 8.** Chroma of vibrated and control tomato groups stored at 10°C and 22°C for a period of 10 days
3.2.3. Firmness. Vibrated and control tomato groups stored at both storage temperature conditions experienced a decline in firmness after 10 days storage period. Tomato firmness varied significantly over all treatments \((p<0.05)\) as can be seen at figure 11. In this study, the firmness ranged from 3.62 kgf to 1.99 kgf. Higher firmness reduction was found among vibrated tomato groups (44.82%) followed by the control tomato group (35.11%) stored at 22°C. Slower firmness loss was shown in tomato stored at 10°C of both vibrated (21.95%) and control (24.98%) groups (Figure 11). The results indicated that the vibration on vibrated tomato group can directly affect its firm state. Generally, transportation can generate a critical issues affecting firmness which highly affected by ripening \([13]\). Furthermore, storage at room temperature can produce a continues loss in tomato firmness due to enzymatic activation and transpiration leading to moisture loss and resulted in cell wall degradation \([16, 25]\). Jung and Park \([7]\) reported high firmness loss on vibrated tomato (33.2%) compared to control tomato (21.9%) storage at 19°C for 30 days. However, the results can indicate that storage at 10°C can delay firmness reduction on vibrated and non-vibrated tomato compared to ambient storage temperature.

Figure 9. \(\text{Hue}^\circ\) of vibrated and control tomato groups stored at 10°C and 22°C for a period of 10 days

Figure 10. Color index (CI) of vibrated and control tomato groups stored at 10°C and 22°C for a period of 10 days
3.2.4. Total soluble solids. Figure 12 shows the measured total soluble solids (TSS) from both tomato groups at both storage temperatures. Initially, the average total soluble solids (TSS) of tomato before treatment was 3.98°Brix then increased following the storage duration. A considerable TSS difference between control and vibrated tomato groups was recorded (p<0.05). For the tomatoes under vibration stress, the increase on TSS stored at room temperature for 10 days was approximately 4.7°Brix, while in non-vibrated group, it increased to approximately 4.5°Brix. Non-vibration group that was stored at 10°C showed a slow increase on TSS with 3.4° Brix on the last day of storage. The results showed that the increasing of TSS was higher in tomato with a vibration stress compared to the control tomato leading to increased ripening in stressed tomato under this condition. In addition, high temperature is also related to rapid alteration on TSS due to the active state of enzymes [3] resulted in starch to sugar alteration [7]. Generally, vibration stress and room temperature storage could accelerate the increase of TSS and respiratory activity rate in vibrated tomato group.

3.3. Observed tomato quality analysis
After 10 days of storage, the percentage of damaged tomato reached to 38.8% particularly in vibrated tomato group stored at 22°C with no percentage of damage in non-vibrated tomato group. Storage at 10°C showed 5.5% of damage in vibrated tomato compared to 0% of damage on the control one. This
damage could be related to vibration exposure as well as compacting that occurred during simulated transport motion which was later increased and activated at room temperature storage.

4. Conclusion
The effect of vibration stress generated from simulated transport and storage temperature on the quality of tomato was determined in this study. Simulated transport experiment showed high vibration acceleration in the middle position of the container. The findings clearly showed that the vibration stress and storage at 22°C highly accelerated the changes in tomato quality like including increased weight loss, decreased lightness, increased redness, decreased firmness, and increased total soluble solids (TSS) for 10 days storage compared to the control group at same temperature. Meanwhile, delayed effect of tomato quality changes was showed in tomato stored at 10°C. Further studies are required to minimize such changes in fresh produce during transpirations.

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