Tomatoes are an important and versatile crop with a short shelf life. Postharvest losses due to fruit decay and handling are reportedly as high as 30–50% globally; therefore, the agricultural sector would benefit from solutions that target the preservation of crops such as tomatoes. In this study, we investigated the potential use of sulfur dioxide \((\text{SO}_2)\) to provide postharvest protection against fungal decay in tomatoes whilst maintaining the quality of tomato fruit. Three tomato varieties packed as bulk \((3–5\) kg) cartons were exposed to \text{SO}_2\)-generating sheets applied as either a top sheet over the fruit or a bottom sheet placed on the base of the carton before packing the fruit on the top. The results show that the application of \text{SO}_2\)-generating sheets reduced the natural progression of decay on ‘Roma’ tomatoes by up to 60% and up to 80% on ‘Rosa’ tomatoes. Only marginal decay control was observed on ‘Round’ tomatoes. The top sheet application rendered the best results, as the application of the bottom sheet resulted in phytotoxicity in the form of \text{SO}_2\ damage. \text{SO}_2 application reduced fruit shrivelling, especially when tomatoes were stored at higher temperatures during their shelf life. The application of \text{SO}_2\ on the tomatoes did not have any negative effects on fruit firmness. The results of this study provide a case to further explore the use of \text{SO}_2\-generating sheets on tomatoes to prevent postharvest decay. Differences in varietal physiology may be key to the successful application of this technology.

**Significance:**
Tomatoes are a crop that is highly susceptible to postharvest decay. These effects lie mainly with the end consumer. Besides the monetary loss of buying a commodity that rots quickly, pathogens infecting tomatoes are known to produce mycotoxins that pose a risk to human health. With food availability and safety concerns, the application of a product that could reduce these concerns would be beneficial to the agricultural sector.

**Introduction**
Tomatoes are a lucrative crop globally, with production exceeding one billion tons in 2021. Unfortunately, total production does not translate to total consumption due to losses that occur along the distribution chain. In South Africa, tomatoes rank second in relation to potatoes as important commodities; they contribute approximately 24% of the country’s annual vegetable production. Commercial tomato-growing regions in South Africa include the provinces of Limpopo, Mpumalanga, KwaZulu-Natal, Eastern Cape and Western Cape, but the Limpopo region remains the largest grower of tomatoes. In 2021, the estimated production of tomatoes was around 530 834 tons, with an estimated gross production value of about ZAR3 031 644. Tomatoes in South Africa are sold as fresh produce through direct sales and exported to neighbouring African countries like Mozambique, Angola and Zambia.

Tomatoes ripen and deteriorate quickly. Ripe tomatoes could last for as long as 2 weeks, but the shelf life is further reduced by decay, injuries and general poor handling. Tomatoes are prone to postharvest decay caused by a complex of fungi such as *Rhizopus stolonifer* (Ehrenb.) Vuill. 1902, *Botrytis cinerea* Pers. 1797, *Alternaria alternata* (Fr.) Keissl. 1912 and *Colletotrichum coccodes* (Wallr.) S. Hughes. Bacterial and viral infections are also common. Statistics relating to postharvest decay of tomatoes are rarely reported as it mostly appears at consumer level. Studies that have investigated the progression of the disease over time report that 74% of ripe fruit will exhibit decay after 2 weeks of storage. Due to quick deterioration, tomatoes cannot be stored for long periods, which puts pressure on producers and retailers to get the fruit to the market as soon as possible. This limits market access and the potential revenue that could be generated if the fruit was able to stay fresh for longer.

Current postharvest handling of tomatoes in South Africa involves hand-picking in the early to mid-mornings and then transporting the tomatoes in open plastic crates to the packhouse. Where infrastructure allows, bins are tipped into a dump tank where the tomatoes are washed in chlorinated water at a dose of about 50–200 ppm. Tomatoes then pass over rollers with light brushes that dry the fruit before being tipped onto the packing tables to be packed either as loose or bagged product, as per retail requirements. Postharvest decay control with fungicides is rare, because application of any product would have to comply with maximum residue levels for safe human consumption. The short shelf life of tomatoes makes it difficult to identify such a postharvest chemical. The chlorine wash provides an effective sanitation method to prevent new infections; however, it does not prevent the proliferation of pathogens which may have already been established through the stem scar.

Sulfur dioxide \((\text{SO}_2)\) is extensively used in the food and beverage industry as an antioxidant and preservative in dried fruits, soft drinks and alcoholic beverages. \text{SO}_2 applications to prevent enzymatic browning in bananas, lemons and apples have been reported. \text{SO}_2 application is also used on fresh fruit such as table grapes to inhibit fungal growth caused by *B. cinerea*. Carroll et al. reported good inhibition of various postharvest pathogens on fresh figs when \text{SO}_2 was applied via fumigation or using \text{SO}_2 pads. Efficacy of \text{SO}_2 in conjunction with controlled atmosphere storage has also shown promising results in reducing decay, extending the shelf life and maintaining the nutritional value of fresh blueberries.
The most common drawback of using SO₂ on soft fruit is the bleaching that may occur. Some studies report that SO₂-generating pads increased the occurrence of bleaching on the skins of figs and grapes. Usually, this happens at wound sites or fresh abscission sites, but excessive exposure can also cause SO₂ damage in the form of sunken areas on fruit surfaces, as well as contribute to premature browning of the grape stems.

SO₂ has long been considered an acceptable food additive; however, with the recent trends of moving away from chemical usage in foodstuffs, SO₂ usage is questioned. Although mostly harmless, exposure to SO₂ could be problematic for people who have sulfite allergies. As requested by the European commission, the European Food Safety Authority published a review that re-evaluated the use of SO₂ and other sulfites as food additives. The panel noted that the current acceptable daily intake of 0.7 mg/kg of body weight could be subjected to review as the actual intake was higher amongst population groups. The panel did not express any concerns of harmful genotoxic, chronic, carcinogenic or negative reproductive effects based on studies done regarding oral exposure; however, a later review in 2022 reported a lower acceptable daily intake of 0.38 mg/kg of body weight.

Currently, there are no SO₂ products registered for postharvest use on tomatoes, globally. The preharvest application of sulfur as a nutrient for tomato plant growth is known. The exposure of tomato plants to SO₂ gas has been studied with negative findings, but research on the postharvest application of SO₂ on fresh tomatoes is a novel concept. In this study, we investigated the potential use of SO₂-generating sheets to provide postharvest protection against fungal organisms that cause decay on tomatoes, whilst maintaining the quality of tomato fruit.

**Materials and methods**

**Fruit**

Two varieties of long-life tomatoes, ‘Round’ and ‘Roma’, and one variety of specialty tomato, ‘Rosa’, were procured from packhouses in the Western Cape, South Africa. The fruit was cut and packed into 5 kg cartons with 3 kg cartons for the smaller ‘Rosa’ tomatoes. Normal packhouse procedures for fruit washing and grading per class and variety were followed. As per these normal procedures, the variety ‘Rosa’ was not subjected to postharvest fruit washing. Class 1 fruit was used for the study.

**Sulfur dioxide and decay control**

The ability of SO₂ to reduce the decay that occurs naturally in tomatoes was investigated. A SO₂-generating sheet was manufactured by Tessara (Pty) Ltd, Cape Town, South Africa, to be used in these experiments. The sheet provided for testing was formulated as a dual-release sheet, with a high first phase of SO₂ emissions (gas levels), followed by a second low-emission phase.

Treatments applied in this trial were as follows: (1) Top sheet – SO₂-generating sheet positioned over the tomatoes in the carton, (2) Bottom sheet – SO₂-generating sheet placed inside the base of the carton with fruit packed on the top, and (3) Control - without any SO₂ sheets in the cartons. A total of six cartons were packed for each treatment group to satisfy statistical requirements. The cartons were stored at 10 °C for either 14 or 21 days, after which quality evaluations were done. For both these time intervals, fruit boxes were evaluated, the decayed and poor-quality fruit was removed, and the remaining good fruit was moved to 18 °C for a further 7 days to mimic shelf-life storage. The trials were done in duplicate for the ‘Round’ and ‘Roma’ tomatoes and in triplicate for the ‘Rosa’ tomatoes over a space of 2 years.

At each evaluation, the amount of fungal decay, SO₂ damage and shrivel was recorded by fruit count for ‘Round’ and ‘Roma’ tomatoes and by fruit weight for the ‘Rosa’ tomatoes. Symptomatic fruits were subjected to isolation and molecular identification of a subset of isolates by sequencing the ITS gene region as described in the literature. Percentage defects were calculated relative to the original numbers of fruit in the carton or the total box weight. In addition, a sample of 10 fruits was taken from each treatment group to evaluate firmness, which was done using a fruit texture analyser. The firmness test was conducted using an 11-mm probe for the large tomatoes and a 3-mm probe for the small tomatoes. Each fruit was pierced once at opposite ends to render a total of two readings per fruit. Average firmness is reported.

**Statistical analysis**

The analysis was conducted independently by the Agricultural Research Council (ARC)-Infrutece Nietvoorbij, Stellenbosch, South Africa. The experimental design was randomised with six replicates for each treatment combination. An analysis of variance (ANOVA) was applied on continuous variables and the output evaluated using SAS® statistical software. The four main parameters evaluated were fungal decay, shrivel, fruit firmness and SO₂ damage. A Shapiro–Wilks test was used to determine deviation from normality. A Fisher’s least significant difference was used to compare treatment means, where a probability level of 5% was deemed significant.

**Results**

A combined average over two trials was calculated for fungal decay, shrivel, fruit firmness and SO₂ damage for the ‘Round’ and ‘Roma’ tomatoes. Three trials were conducted for the ‘Rosa’ tomatoes, with all being statistically different; therefore, the results are discussed separately. Varieties were not compared and will be discussed separately. All data reported for shelf life are cumulative.

**Decay control**

ANOVA interactions were significant for parameters of decay (p < 0.0001) and decay inhibition (p = 0.04) in Roma tomatoes (Table 1). The control sets throughout the storage period had significantly higher decay incidence (21–67%) than tomatoes treated with the SO₂ sheets (8–55% decay incidence; Figure 1). The effect of the treatments continued for up to 7 days after cold storage, even after the sheets had been removed, indicating that the initial SO₂ application has an ongoing effect and that the protection against decay will continue in the absence of SO₂ exposure, thereby extending the shelf life of ‘Roma’ tomatoes. With regard to sheet placement, it was noted that both the top and bottom placed sheets effectively reduced the decay. The results infer that a bottom sheet will be more beneficial with longer storage times, as at 21 days of cold storage, tomatoes treated with a bottom placed sheet had significantly less decay than the tomatoes treated with a top sheet.

<table>
<thead>
<tr>
<th>Treatment × Position × Shelf</th>
<th>‘Roma’ *</th>
<th>‘Round’ *</th>
<th>‘Rosa’ Trial 1</th>
<th>‘Rosa’ Trial 2</th>
<th>‘Rosa’ Trial 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decay</td>
<td>&lt;0.0001</td>
<td>0.39</td>
<td>0.00</td>
<td>0.07</td>
<td>0.32</td>
</tr>
<tr>
<td>Decay inhibition</td>
<td>0.04</td>
<td>0.31</td>
<td>0.30</td>
<td>0.21</td>
<td>0.34</td>
</tr>
<tr>
<td>SO₂ damage</td>
<td>0.32</td>
<td>0.40</td>
<td>0.00</td>
<td>0.67</td>
<td>0.36</td>
</tr>
<tr>
<td>Shrivel</td>
<td>0.94</td>
<td>0.30</td>
<td>0.00</td>
<td>0.97</td>
<td>0.29</td>
</tr>
</tbody>
</table>

*Average of two trials. p ≤ 0.05 indicates significant interactions between evaluation parameters.

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An ANOVA for 'Round' tomatoes indicated no significant differences in decay (Table 1). The 'Round' tomatoes were presented with high decay levels throughout the trial. After 14 days at 10 °C, decay recorded on the 'Round' tomatoes was between 22% and 25% (Figure 1). At this point, there was no statistical difference between the treated and control fruit. When moved to shelf life, the tomatoes treated with a top placed sheet had significantly lower decay than the control fruit; however, the decay was high (62%). After extended storage (21 days) at 10 °C, the fruit treated with the bottom sheet showed the least amount of decay, but this was not statistically different to the other groups.

The ANOVA for 'Rosa' tomatoes showed that all three trials conducted were different; therefore, the results could not be combined, and the trials need to be discussed separately (Table 1). In the first trial, there was no significant interaction between all parameters evaluated during initial storage; however, the interaction was significant when tomatoes were moved to shelf life. In the second and third trials, interactions were not significant for both initial storage and shelf life.

The trials for 'Rosa' tomatoes differed significantly with the amount of decay observed (Figure 2). The first trial showed a fair amount of decay with the controls reaching up to 30% decay during the initial storage, whilst Trials 2 and 3 recorded between 0.9% and 7% decay during the same time. In Trial 1, there was no significant difference in decay between SO\textsubscript{2} treatments and the control during the initial 7-day storage evaluation and subsequent shelf life, although tomatoes treated with SO\textsubscript{2} had about 10% less decay than the control during initial storage. Exposure to SO\textsubscript{2} sheets for up to 14 days showed that treated tomatoes had significantly less decay than the control. The bottom sheet proved...
was noted with the application of the bottom sheet over the long-term storage period. This value is less than 50%; therefore, SO$_2$ treatments on ‘Round’ tomatoes cannot be recommended as a viable treatment option at present.

Decay inhibition differed between trials conducted on ‘Rosa’ tomatoes. In the first trial, application of a top sheet inhibited decay after 7 days by 22% and by 26% after 14 days. A bottom sheet inhibited decay after 7 days by 33% and by 68% after storage for 14 days. In the second trial, SO$_2$ application was most successful during the 7-day storage period. During this time, a top sheet reduced decay by 81% relative to the control and a bottom sheet reduced decay on ‘Rosa’ tomatoes by 78%. The sheets did not seem to be effective after 14 days. In the third trial, the top sheet SO$_2$ application was most successful, inhibiting decay during the first 7 days by 48% and then by 80% when used for a period of 14 days (Table 3). Isolates from all three varieties that were subjected to molecular identification were found to be identical to GenBank references of Alternaria spp. (KP125281).

**SO$_2$ damage**

When the concentration of SO$_2$ gas in the carton is too high, or the gas becomes localised to certain areas, it can cause SO$_2$ bleaching or damage to the fruit.$^{22}$ The percentage of SO$_2$ damage that was recorded on ‘Roma’ and ‘Round’ tomatoes after the 14- and 21-day cold storage periods and subsequent shelf life is presented in Figure 3. A significant amount of SO$_2$ damage was recorded in cartons with a bottom sheet when compared to other treatments. Although significantly higher than

### Table 2: Percentage decay inhibition by SO$_2$ treatments on ‘Roma’ and ‘Round’ tomatoes after 14 (D14) and 21 (D21) days in cold storage at 10 °C and the respective 7-day shelf-life period at 18 °C

<table>
<thead>
<tr>
<th>Variety</th>
<th>Treatment / storage</th>
<th>D14 at 10 °C</th>
<th>D14 + D7 at 18 °C</th>
<th>D21 at 10 °C</th>
<th>D21 + D7 at 18 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Roma’</td>
<td>Top sheet</td>
<td>63.96 a</td>
<td>58.94 a</td>
<td>30.32 bc</td>
<td>17.59 c</td>
</tr>
<tr>
<td></td>
<td>Bottom sheet</td>
<td>54.22 a</td>
<td>65.59 a</td>
<td>60.67 a</td>
<td>38.70 b</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0.00 d</td>
<td>0.00 d</td>
<td>0.00 d</td>
<td>0.00 d</td>
</tr>
<tr>
<td>‘Round’</td>
<td>Top sheet</td>
<td>–4.90 bc</td>
<td>13.24 ab</td>
<td>–3.11 bc</td>
<td>2.21 bc</td>
</tr>
<tr>
<td></td>
<td>Bottom sheet</td>
<td>–10.19 c</td>
<td>10.89 ab</td>
<td>22.57 a</td>
<td>13.70 ab</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0.00 bc</td>
<td>0.00 bc</td>
<td>0.00 bc</td>
<td>0.00 bc</td>
</tr>
</tbody>
</table>

The same lettering indicates no significant difference (p > 0.05) according to Fisher’s least significant difference test. Data presented represent the average of two trials.

### Table 3: Percentage decay inhibition by SO$_2$ treatments on ‘Rosa’ tomatoes after 7 (D7) and 14 (D14) days in storage and the respective 7-day shelf-life period at 18 °C

<table>
<thead>
<tr>
<th>Trial number</th>
<th>Treatment / storage</th>
<th>D7</th>
<th>D7_Shelf life</th>
<th>D14</th>
<th>D14_Shelf life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>Top sheet</td>
<td>22.26 b</td>
<td>–26.05 d</td>
<td>28.62 b</td>
<td>28.62 b</td>
</tr>
<tr>
<td></td>
<td>Bottom sheet</td>
<td>33.72 b</td>
<td>24.59 bc</td>
<td>66.50 a</td>
<td>68.50 a</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0.00 b</td>
<td>0.00 cd</td>
<td>0.00 b</td>
<td>0.00 cd</td>
</tr>
<tr>
<td>Trial 2</td>
<td>Top Sheet</td>
<td>81.07 a</td>
<td>81.07 a</td>
<td>–98.70 b</td>
<td>–125.7 b</td>
</tr>
<tr>
<td></td>
<td>Bottom sheet</td>
<td>78.16 a</td>
<td>78.16 a</td>
<td>9.94 ab</td>
<td>9.94 ab</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0.00 ab</td>
<td>0.00 ab</td>
<td>0.00 ab</td>
<td>0.00 ab</td>
</tr>
<tr>
<td>Trial 3</td>
<td>Top sheet</td>
<td>–48.70 a</td>
<td>38.61 a</td>
<td>80.53 a</td>
<td>55.71 a</td>
</tr>
<tr>
<td></td>
<td>Bottom sheet</td>
<td>–98.98 b</td>
<td>–147.10 b</td>
<td>30.70 ab</td>
<td>30.88 a</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>0.00 ab</td>
<td>0.00 a</td>
<td>0.00 ab</td>
<td>0.00 a</td>
</tr>
</tbody>
</table>

The same lettering indicates no significant difference (p > 0.05) according to Fisher’s least significant difference test.
the top sheet treatments, it must be noted that the overall value of SO₂ damage at its highest was a mere 5.4% on 'Roma' tomatoes.

The SO₂ damage was more pronounced on the 'Round' tomatoes (Figure 3). After 14 days, the incidence of SO₂ damage ranged from 0.89% for the top sheet application to 16.21% for the bottom sheet application. A significant increase in SO₂ damage was noted on tomatoes that were treated with a bottom sheet. Inexplicably though, the continued exposure to the bottom pads after 21 days in cold storage yielded less SO₂ damage on fruit than at 14 days.

The results for SO₂ damage on 'Rosa' tomatoes echo that of the other two varieties. Minimal SO₂ damage was observed with application of a top sheet, and high SO₂ damage (up to 18%) was observed when a bottom sheet was used across the three trials (Figure 4). For all varieties, the SO₂ damage that was observed during the initial storage did not develop further after shelf life. In cases where increased amounts during shelf life are noted, this could be due to inadequate sorting during the initial inspection.

**Shrivel**

Following the 2 weeks at a 10 °C storage regime, the amount of shrivel on 'Roma' tomatoes did not differ between treatments; however, when moved to shelf life, the SO₂-treated tomatoes had more shrivel than the control tomatoes (Figure 5). Over the 21-day storage period, however, SO₂-treated tomatoes had significantly less shrivel than the control fruit; and during the respective shelf life, tomatoes treated with a top sheet showed significantly less shrivel than the bottom sheet treated tomatoes and the control tomatoes.

![Figure 3: Percentage sulfur dioxide damage observed on 'Roma' and 'Round' tomatoes after 14 (D14) and 21 (D21) days in cold storage at 10 °C and the respective 7-day shelf-life period at 18 °C. Bars with the same lettering do not differ significantly (p > 0.05) according to Fisher’s least significant difference test. Data presented are the average of two trials.](image)

![Figure 4: Percentage sulfur dioxide damage recorded on 'Rosa' tomatoes after 7 (D7) and 14 (D14) days of initial storage with SO₂ sheets and a further 7 days at shelf life. Temperature was kept constant at 18 °C for the duration of the trials. Bars with the same lettering do not differ significantly (p > 0.05) according to Fisher’s least significant difference test.](image)
For ‘Round’ tomatoes, the results were mostly insignificant except for the 21-day shelf-life period, where tomatoes treated with SO\(_2\) applied as a top sheet were significantly less shrivelled than the bottom sheet treated and control tomatoes. Overall, the shrivel on ‘Round’ tomatoes was minimal throughout the trial (Figure 5).

For ‘Rosa’ tomatoes, the results varied between trials (Figure 6). In the first trial, no significant difference in shrivel was observed among treatments after the first 7 days; however, during the shelf life, tomatoes treated with a top sheet had significantly less shrivel than the bottom sheet treated and control tomatoes. After 14 days, the converse was shown, with the controls having the least amount of shrivel. In the third trial, tomatoes treated with SO\(_2\) consistently had less shrivel than the controls throughout the trial.

**Firmness**

Prior to the initial cold storage, samples were taken for firmness testing to establish a baseline representing the firmness of the fruit on arrival. Measurements at each initial evaluation were then compared to this baseline. For all varieties, a natural decline in firmness was observed when comparing the readings for the control to the arrival reading (Table 4).

For ‘Roma’ tomatoes, firmness values for all treatments were similar throughout the trial; however, in the 21-day cold storage, tomatoes treated with a top sheet were significantly less firm than the controls. For the ‘Round’ tomatoes, there was also a natural decline in firmness relative to the arrival readings, as noted in the controls. However, it was observed that tomatoes treated with a bottom sheet maintained readings relative to that of the arrival quality for up to 21 days in cold storage. ‘Rosa’ tomatoes held their firmness throughout the trial period of...
Decay symptoms observed in these trials were presented primarily as water-soaked and black sunken lesions that are consistent with black mould infection caused by Alternaria spp. Decay on ‘Roma’ tomatoes was reduced by both the top and bottom sheet applications. The results suggest that short-term storage (14 days) of ‘Roma’ tomatoes benefits from using a top SO$_2$ sheet, whilst for long storage periods (21 days), a bottom sheet would be better. However, use of a bottom sheet does present complications because of SO$_2$ damage that can occur. The ‘Round’ tomatoes used in this study seemed to be sensitive to pathogen attack. Considerable amounts of decay were observed throughout storage and shelf life. Decay on ‘Round’ tomatoes was not shown to be statistically reduced with the application of a SO$_2$ sheet, even though numerical values of the treatments were lower than the control. Decay on ‘Rosa’ tomatoes differed between trials conducted. This shows the natural variation that occurs throughout the year and between seasons. Due to the availability of tomatoes, the trials were conducted over a period of 1 year (2020–2021). Tomatoes for the first trial were sourced in November, which is the start of rising summer temperatures. The conditions in the Western Cape over this time are often conducive to pathogen development, which could be what was observed. The second trial was conducted in September (early spring). These were early season fruit and may have been more steady and less prone to pathogen attack. The third trial was conducted in November 2021, and whilst decay was present, the overall inoculum level was low. Literature suggests that the time of harvest has a significant impact on fruit quality and that there are definitive differences between tomatoes harvested in autumn and spring. In addition to the timing of harvest, the reduced inoculum pressure over the course of the year could be attributed to preharvest practices on the farm. Natural variation in decay over time is a possibility, and played a role in these trials. Overall, though, when looking at the effect of an SO$_2$-generating sheet on the reduction of natural decay on ‘Rosa’ tomatoes, both the top and bottom SO$_2$ sheet applications were useful in reducing decay, with results favouring the use of a top sheet application for this variety.

We have shown that the application of a SO$_2$ sheet during storage also had an impact on the decay that developed after shelf life when the SO$_2$ sheet was removed. This was consistent for all varieties. Whilst decay did develop, it was much less than what was recorded on the controls. This is explained in that SO$_2$ sterilises the fruit surface and can kill off spores and mycelia on the fruit surface; however, it has less impact on latent infections which come into play in the absence of SO$_2$ (removal of sheets). The further development of decay during the shelf life indicates that residue left on the fruit surface after sheets are removed is not adequate to prevent the proliferation of fungi.

We did not directly compare varieties; however, the variations were apparent. Variations in decay amongst tomato varieties have been previously reported. Sinha et al. reported that, under ambient conditions after 16 days, the variety ‘Sofol’ showed 21% decay whilst the variety ‘Roma’ had 43% decay. ‘Sofol’ is a round-type tomato, and with that in mind, we see the opposite occurrence with regard to decay patterns in this study, perhaps due to differences in cultivation practices and climatic regions.

An accumulation or localisation of SO$_2$ gas can cause SO$_2$ bleaching or damage to the fruit. Through the sorting process, all defects observed at the cold storage evaluation were removed before placing the fruit at shelf life. When the fruit is still cold, the condensation that forms on the fruit surface makes it hard to see slight SO$_2$ damage. Therefore, any SO$_2$-damaged tomatoes observed during the shelf life can be attributed to improper sorting at the initial cold storage evaluation.

A key finding from these trials is that the bottom sheet yielded more SO$_2$ damage than the top sheet. The damage observed from the bottom sheet could be attributed to the increased pressure of fruits sitting on top of each other and pressing onto the bottom sheet. This is the most obvious explanation, as damage seen with the top sheet application was not as pronounced. With the application of a top sheet, the fruits are not pressing onto the sheet, even if...
contact is made. For all varieties, the amount of SO₂ damage observed with the application of a top sheet was negligible (less than 1%); in comparison, SO₂ damage from a bottom sheet was up to 5% on ‘Roma’ tomatoes, up to 16% on ‘Round’ tomatoes and up to 18% on ‘Rosa’ tomatoes. SO₂ damage can have various manifestations on fruit, the most common being bleaching (discolouration) and fruit pitting.²² Both these symptoms were observed on tomatoes to varying degrees. In some instances, only a slight discolouration around the stem scar was visible; however, where pressure was applied, as with the application of a bottom sheet, the fruit showed signs of pitting. Unfortunately, whilst a slight discolouration can be overlooked, pitting would render the tomatoes unmarketable due to appearance.

Tomatoes have a high water content and are prone to shrinkage due to moisture loss after harvest.²⁶ Of the three varieties used in this trial, ‘Roma’ and ‘Rosa’ tomatoes were most affected by shrivelling, during the shelf-life storage phase. In contrast, shrivel on ‘Round’ tomatoes was minimal. This could be due to the initial water content of the varieties and the respective respiration rates. With ‘Roma’ tomatoes, short-term exposure to SO₂ had no effect on shrivelling; however, long-term exposure to SO₂ did reduce the incidence of shrivel. A similar pattern was observed with the ‘Round’ tomatoes. ‘Rosa’ tomatoes benefitted from SO₂ exposure throughout the trial period.

In conclusion to a study on the firmness of tomatoes, Batu²⁷ proposed two firmness readings for large tomatoes. The first is for fruit marketed at retail level, which should render a firmness reading greater than 1.45 N/mm (0.15 kg), and the second is value for tomatoes for home consumption, which should be greater than 1.28 N/mm (0.13 kg). The firmness of both large tomato varieties recorded in this study was well above these readings, even for the control fruit; the ‘Roma’ tomatoes were firmer than the ‘Round’ tomatoes. This finding corresponds with the literature that states that processing tomatoes like ‘Roma’ tend to be firmer and last longer than fresh market tomatoes. Varietal differences in firmness are accounted for by properties such as cell wall composition.²⁸ A gradual decline in firmness was observed across all three varieties used in this study, and the results obtained show that SO₂ exposure did not negatively affect this quality parameter.

Conclusion

The results confirm that a SO₂ sheet applied as a top sheet can be used to effectively reduce decay by a minimum of 58% on ‘Roma’ tomatoes when refrigerated at 10 °C for up to 14 days and then exposed to ambient temperature for another 7 days. Alternatively, a bottom sheet application can reduce decay by 60% if tomatoes are kept refrigerated for 21 days, but the potential SO₂ damage must be considered. ‘Round’ tomatoes in this study only benefitted from a marginal reduction in decay by the application of a bottom sheet. Continuous refinement of this product for use on ‘Round’ tomatoes will need to focus on reducing the SO₂ damage. The potential for decay control in ‘Rosa’ tomatoes is high because, even though trials differed, a decay inhibition of up to 80% was obtained at different intervals.

The outcome of this study builds a strong case for the use of SO₂-generating sheets to be used on certain tomato varieties under commercial conditions for the purpose of decay reduction during storage. As an added benefit, the use of SO₂-generating sheets may assist with reduced shrivelling of tomatoes during storage. Furthermore, SO₂ does not negatively affect the firmness of tomatoes during storage.

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Competing interests

We have no competing interests to declare.

Authors’ contributions

C.K.D.-S.: Conceptualisation; methodology; data collection; sample analysis; validation; writing; project management. J.C.M.-H.: Student supervision; editing of manuscript. F.A.V.: Student supervision; project leadership; funding acquisition. C.L.L.: Student supervision.

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