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Sulphur dioxide sheet and cold storage synergy for post-harvest management of Thompson seedless grapes (*Vitis vinifera*)

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ABSTRACT

Purpose: This study examined the influence of various storage conditions on Thompson seedless (*Vitis vinifera*) grapes quality. **Research method:** Grapes were stored under four conditions: control (room temperature i.e., 20-22°C, no SO_2), T1 with SO_2 sheets at room temperature i.e., 20-22°C, T2 with SO_2 sheets in cold storage at 1°C and T3 without SO_2 sheets in cold storage at 1°C. Changes in acidity, total soluble solids (TSS), total anthocyanin content, total phenols, sugars (glucose and fructose), trans-resveratrol, decay %, weight loss % and antioxidant activity were monitored over 60 days. **Findings:** The findings revealed a synergistic effect between SO_2 and cold storage. Grapes stored with both SO_2 sheets and cold storage (T1) exhibited the slowest decline in anthocyanin, phenols and antioxidant activity of 211.06 mg/L, 2102.39 mg/L and 7.19 mM DPPH, respectively after 60 days. T1 grapes found to have slower reduction in sugars and trans-resveratrol concentration i.e., 15.47 to 15.37 g/100mL and 695 to 516 µg/g, respectively compared to control samples 15.47 to 14.81 g/100mL and 695 to 500 µg/g, respectively. **Research limitations:** The study focused solely on storage conditions of Thompson seedless variety grapes, limiting the generalizability of the findings to different grape varieties and maturity levels. **Originality/value:** These results highlighted the importance of proper storage techniques, particularly the combined use of SO_2 and cold storage, for maintaining grape quality and extending shelf life.

INTRODUCTION

Fruit production is one major way that the agricultural industry contributes to the global economy (Mohamed et al., 2011). Grapes (*Vitis vinifera*) are among the most economically significant fruits. Post-harvest losses continue to be a significant obstacle for grape growers and supply chain operators across the globe (Zhou et al., 2017; Mirfatah et al., 2024). In addition to having an effect on financial gains, post-harvest losses waste resources increase food insecurity and environmental damage (Ali et al., 2021; Moradinezhad & Ranjbar, 2023). The goal of post-harvest management techniques is to reduce losses and preserve fruit quality from harvest to eating. When it comes to prolonging the shelf life of perishable fruits such as grapes, cold storage is one of the most useful strategies used (Chaves & Zaritzky, 2018). Fruit quality and freshness are preserved through the slowing down of physiological processes including respiration and ripening during cold storage (Brizzolara et al., 2020). Cold storage might not be enough to stop all degradation and deterioration, though, particularly in fruits like grapes that are prone to oxidative browning and fungal infections.

The food industry frequently uses sulphur dioxide (SO_2) as a preservative because of its antibacterial and antioxidant qualities. Because of its ability to stop enzymatic browning and fungal growth, it is a great option for improving grape quality after harvest (Palou et al., 2010). The SO_2 sheets contain sodium metabisulfite enclosed between paper sheets of differing permeability. When moisture within the package of grapes is absorbed by the pads, it reacts with the sulphite, releasing SO_2. The quick-release part of the pad gives a flush of SO_2, which peaks after about 24 hours and then diminishes in about a week (Lichter et al., 2008). In the past, SO_2 has been applied through fumigation or by using sachets or pads that release SO_2 inside storage containers. These techniques do have certain drawbacks, such as unequal SO_2 dispersion and possible health risks from prolonged exposure to sulphur dioxide. New developments in post-harvest technology have resulted in the creation of sheets that release sulphur dioxide and are intended for use in cold storage facilities. With the regulated release of SO_2 offered by these novel sheets, human exposure to the gas is reduced and equal dispersion inside the storage space is ensured. Sulphur dioxide sheets and cold storage work together to provide a synergistic strategy to grape post-harvest management that successfully addresses enzymatic deterioration as well as microbiological spoilage.

Although combining sulphur dioxide sheets with cold storage may have advantages, there was a lack of research on how well these two approaches work together to maintain grape quality during post-harvest handling. Previous studies have mainly looked at individual methods rather than how they work together as a synergistic whole. Therefore, more thorough research is required to determine how well this integrated approach works to prolong grape shelf life and preserve grape quality during storage and transportation. By assessing the complementary benefits of cold storage and sulphur dioxide sheets on grape post-harvest management, this research seeks to close this gap. The research aims to clarify the mechanisms behind the combined action of these techniques and their influence on important quality indicators such fruit firmness, colour retention, microbial load and sensory qualities of grapes under cold storage conditions.

MATERIALS AND METHODS

Thompson seedless grapes (*Vitis vinifera*) were procured from the vineyards in the Nashik, Maharashtra, India. According to AGMARK maturity requirements, grapes must have a minimum TSS of 16 °Brix and a sugar-to-acid ratio of 20:1 (Apeda, 2021). Grapage (grape

guard sheets/SO_2 pads) SO_2 sheets with maximum residue limit of 10 ppm sulphite and absorbent papers were purchased from JK Enterprise, Nashik, Maharashtra, India.

Grape bunches that met maturity requirements were chosen for vineyard harvesting. Before the temperature of the berries rose over 20°C, the grapes were harvested in the early morning. Expert harvesters with sharp scissors and soft rubber gloves had completed the task. Grapes were harvested and then taken to the packhouse one day before they were picked. There, broken berries and malformed, decaying, small, and discoloured berries were removed by cutting their pedicels off of the chosen bunches using long-nosed scissors, and grapes were graded. Grapes were graded and then placed in plastic clamshell punnets. To prevent the grapes from bruising, a layer of bubble pad and protective liner was positioned at the bottom of the box after the punnet was filled. General steps of packaging of harvested grapes are shown in Figure 1.

Grapes packed without sulphur dioxide sheet and stored at room temperature

The grape punnet was put inside a box, sealed with a liner, and fresco pad without sulphur dioxide sheet. Grapes were kept in dark at room temperature at 20-22°C after packaging (control). Grapes were taken to laboratory for the quality analysis at 10 days' interval up to 60 days. These samples were used as a control sample to compare with other treatments.

Grapes packed with sulphur dioxide sheet and stored at cold storage

The grape punnet was put inside a box, sealed with a liner, and covered with a sheet of sulphur dioxide and a fresco pad. Grapes were kept for pre-cooling after packaging in order to lower their temperature to less than 4°C in 6 to 8 hours. The purpose of pre-cooling is to lower field heat. Grapes were refrigerated in cold storage at 1°C and 90-95% RH in dark after being pre-cooled (T1). Grapes were taken to laboratory for the quality analysis at 10 days' interval up to 60 days.

Grapes packed with sulphur dioxide sheet and stored at room temperature

The grape punnet was put inside a box, sealed with a liner, and covered with a layer of sulphur dioxide and a fresco pad. Grapes were kept in dark at room temperature at 20-22°C after packaging (T2). Grapes were taken to laboratory for the quality analysis at 10 days' interval up to 60 days.

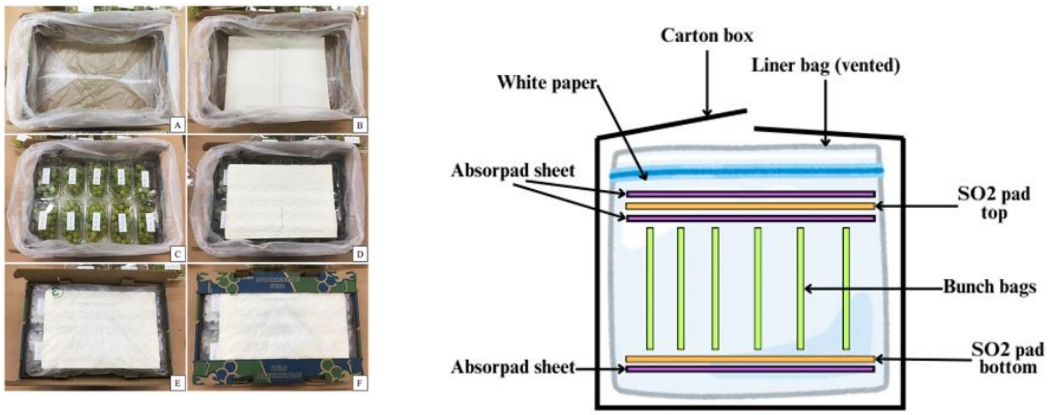

Fig. 1. Packaging steps and diagram for harvested grapes adopted and modified from de Aguiar et al. (2023).

Grapes packed without sulphur dioxide sheet and stored at cold storage

The grape punnet was placed within a box, lined, and fresco pad covered without sulphur dioxide sheer. After packaging, grapes were kept for pre-cooling in a cooling chamber for a minimum of 6 to 8 hours to bring their temperature down below 4°C. Pre-cooling is done to reduce field heat. Grapes were pre-cooled and then placed in cold storage at 1°C and 90-95% RH in dark (T3). At 10 days' interval up to 60 days, grapes were brought to laboratory for analysis.

Analysis of grapes quality parameters

Titratable acidity was measured using an automatic titrator (Mettler Toledo EasyTitration, Mumbai, India) where results were measured in % of malic acid. Total soluble solids (TSS) was measured using a hand-held refractometer (Erma, Tokyo, Japan) with results measured in °Brix. Total anthocyanin content was measured using UV-vis spectrophotometer (Jenway® 6305, Mumbai, India) at 520 and 700 nm expressed in mg/L, method described by Pastrana-Bonilla et al. (2017). Total phenols were analysed by Folin-Ciocalteu method described by Way et al. (2020) using UV-vis spectrophotometer at 765 nm expressed in mg/L. Sugars i.e., glucose and fructose presented in grapes were estimated by following the method described by Albalasmeh et al. (2013) using sulphuric acid and UV-vis spectra at 315 nm. The antioxidant capacity of the sample extract was measured as per the method suggested by Brand-Williams et al. (1995) and modified by Sanchez-Moreno et al. (1998). DPPH is one of the stable and commercially available organic nitrogen radicals and has UV-vis absorption maxima at 515 nm. On reduction of the colour solution fades and the reaction progress is monitored with a spectrophotometer at 515 nm. In methanolic solution (0.1 ml) of sample extract (15 mg/ml) added to 3.9 ml of DPPH (0.025g/ l) in methanol and absorbance measured at 515 nm. The absorbance was measured until the reaction reached a plateau (steady state). Estimation of trans-resveratrol was carried out using the method described by Camont et al. (2009) at 304 nm uv-viz absorption in uv-vis spectrophotometer. Decay % and weight loss % were calculated using the following formulas (1 and 2).

$$\text{Decay \%} \frac{\text{Decayed grapes (g)}}{\text{Initial weight (g)}} \times 100 \qquad (1)$$

$$\text{Weight loss \%} \frac{\text{Measured weight (g)}}{\text{Initial weight at the beginning of storage (g)}} \times 100 \qquad (2)$$

Statistical analysis

All the data were expressed as mean ± standard deviation (SD) of three determinations. Data obtained during the study was analysed and Completely Randomized Design (CRD) was performed using Design Expert 13 software via a one-way analysis of variance (ANOVA). At each 10-day interval (up to 60 days), randomly selected three number of punnets from each treatment were analysed for quality parameters. P values of less than 0.05 ($P < 0.05$) were considered as significant.

RESULTS AND DISCUSSION

Grapes were packed according to steps described by de Aguiar et al. (2023) as shown in Figure 2 with modification in conditions. Packed grapes with SO_2 sheets were stored in cold storage and room temperature. Grapes without SO_2 sheets were stored in cold storage. Control sample were stored at room temperature without SO_2 sheets. Physico-chemical analysis of grapes stored in different conditions for 0 days and 60 days are presented in Table 1.

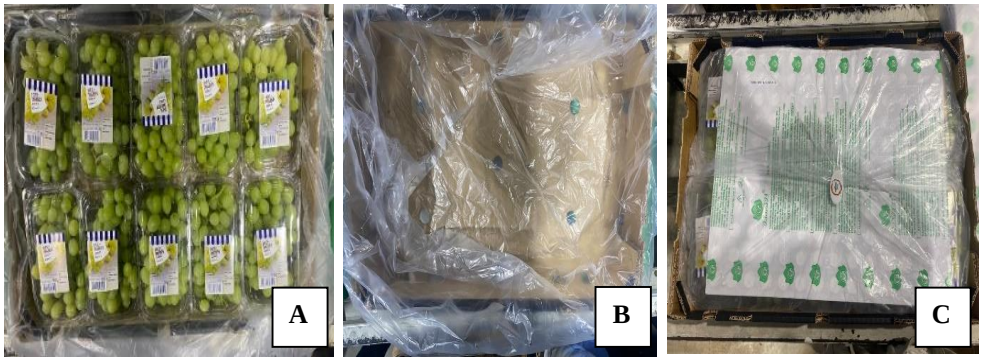

Fig. 2. Grapes packed in different conditions (A) control, (B) without SO_2 sheet, and (C) with SO_2 sheet.

Table 1. Physico-chemical parameters of grapes stored in different conditions.

Parameter	Acidity (% malic acid)		Sugar (° Brix)		Total anthocyanins (mg/L)		Total phenols (mg/L)		DPPH antioxidant activity (mM)	
Days	0	60	0	60	0	60	0	60	0	60
Control	0.92 ±0.01	0.78 ±0.01	17.50 ±0.11	14.56 ±0.15	212.33 ±0.15	190.00 ±0.13	2115.12 ±0.20	1856.25 ±0.11	7.22 ±0.04	5.76 ±0.01
(T1)	0.92 ±0.01	1.03 ±0.02	17.50 ±0.11	16.50 ±0.10	212.33 ±0.15	211.06 ±0.22	2115.12 ±0.20	2102.39 ±0.12	7.22 ±0.01	7.19 ±0.02
(T2)	0.92 ±0.01	1.12 ±0.02	17.50 ±0.11	14.80 ±0.12	212.33 ±0.15	205.25 ±0.10	2115.12 ±0.20	2085.74 ±0.20	7.22 ±0.01	7.10 ±0.01
(T3)	0.92 ±0.01	1.95 ±0.02	17.50 ±0.11	15.66 ±0.10	212.33 ±0.15	199.22 ±0.10	2115.12 ±0.20	1992.56 ±0.12	7.22 ±0.02	6.84 ±0.05

T1 = SO_2 sheet with cold storage grapes, T2 = SO_2 sheet at room temperature grapes, T3 = Without SO_2 sheet at cold storage grapes.

Changes in acidity

Changes in acidity were measured as the percentage of malic acid shown in Figure 3. Control samples shown the decrease in acidity from 0.92% to 0.78%. Fresh grapes, not being subjected to cold storage, would have their natural metabolic processes ongoing. These processes include the conversion of malic acid to other forms of acid or to energy, led to a decrease in the percentage of malic acid over time. In T1 samples, the acidity slightly increased from 0.92% to 1.03%. The increase in acidity could be due to the cold storage slowing down the metabolic processes, including the conversion of malic acid to other forms (Yan et al., 2022; Deng et al., 2005). The use of SO_2 sheets helped in inhibiting microbial activity that could otherwise contribute to the breakdown of malic acid (Zhan et al., 2023; Chervin et al., 2012). In T2 samples, the acidity increased from 0.92% to 1.12%. The room temperature allowed more active metabolic processes, led to a higher conversion rate of other acids into malic acid. The SO_2 sheet, while inhibiting microbial activity, would not have been as effective in slowing down these processes as cold storage (Zhan et al., 2023; Lakso & Kliewer, 1975). In T3 samples, the acidity increased significantly ($p < 0.05$) from 0.92% to 1.95%. Without the SO_2 sheet, the grapes were more exposed to microbial activity which could lead to the production of more malic acid (Ahmed et al., 2018). However, the cold storage slows down these processes, which is why the increase in acidity is not as drastic as it could have been at room temperature.

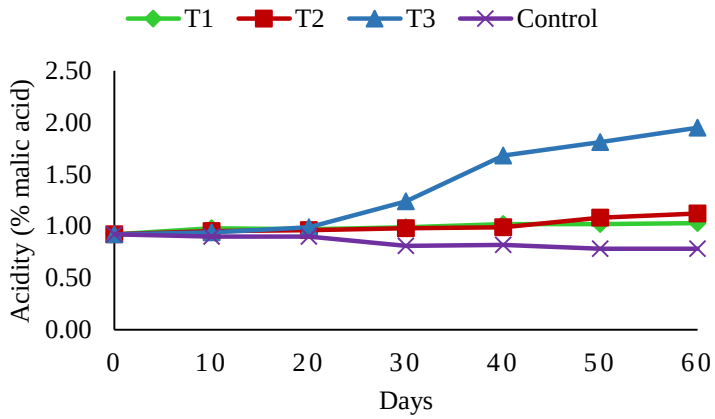

Fig. 3. Changes in acidity (% malic acid) of the grapes stored at different conditions.

(T1 = SO_2 sheet with cold storage grapes, T2 = SO_2 sheet at room temperature grapes, T3 = Without SO_2 sheet at cold storage grapes, Control = Without SO_2 sheet at room temperature grapes).

Changes in total soluble solids and sugars

It was found that the sugar content (TSS) in grape juice decreased over time during storage, regardless of the storage conditions. This decrease was significant from 17.5 to 14.8 °Brix in grapes stored at room temperature with SO_2 sheets (T2) and in grapes stored in cold storage without SO_2 sheets (T3) i.e., 15.66 °Brix after 60 days. Fresh grapes also witnessed a decrease in sugar content over time as shown in Figure 4. SO_2 sheet combined with cold storage (T1) gave the highest preservation of TSS i.e., 16.5 °Brix after 60 days.

Grapes continue to respire after harvest like the other fruits and berries. During respiration, sugars broken down into carbon dioxide and water, which resulted a decrease in sugar content (Zhong et al., 2023). The use of SO_2 sheets found to slow down the decrease in sugar content. SO_2 is a common preservative used in winemaking and other food industries due to its antioxidant and antimicrobial properties. It can inhibit the activity of many enzymes, slowing down the metabolic activities in the grapes and thus resulted the decrease in sugar content. Cold storage also seems to slow down the decrease in sugar content by reducing the rates of respiration, fermentation and other metabolic activities (Vlassi et al., 2018). Similar results were observed by Ahmadi Soleimanie and Vafaee (2023), where they found that total soluble solids (TSS) content of Iranian grape cultivars slowly increased during cold storage up to day 21, particularly in the Sahebi cultivar. In another study by Leng et al. (2022) shown that grapes stored at low temperature, significantly reduced the decay incidence, weight loss, rachis browning.

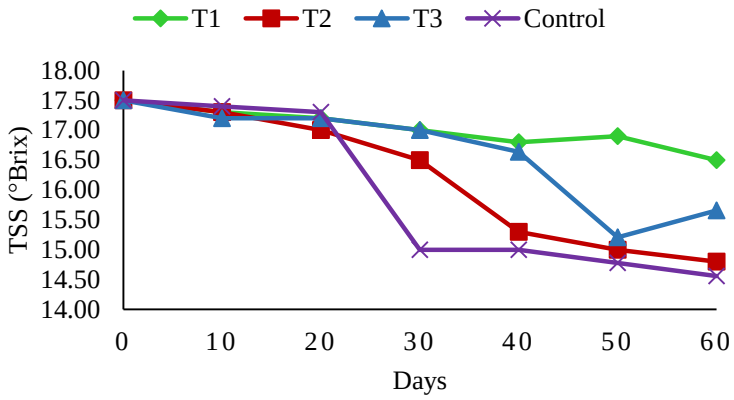

Fig. 4. Changes in TSS of grapes stored in different conditions.

(T1 = SO_2 sheet with cold storage grapes, T2 = SO_2 sheet at room temperature grapes, T3 = Without SO_2 sheet at cold storage grapes, Control = Without SO_2 sheet at room temperature grapes).

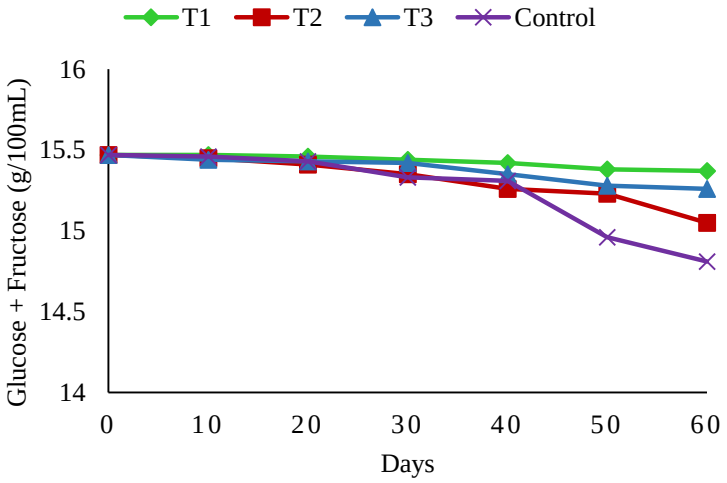

Fig. 5. Changes in grapes sugars (glucose and fructose) in different conditions.

(T1 = SO_2 sheet with cold storage grapes, T2 = SO_2 sheet at room temperature grapes, T3 = Without SO_2 sheet at cold storage grapes, Control = Without SO_2 sheet at room temperature grapes).

In control samples, the sugar content decreased was significant ($p < 0.05$). Without the protective effects of SO_2 and cold storage, the metabolic processes of grapes and microbial activity occurred rapidly, which led to a rapid decrease in sugar content. The Brix level in control samples decreased quite significantly from 17.5 to 14.56 (Fig. 5). This indicated a gradual reduction in sugar content, which was a result of faster metabolic processes at room temperature without SO_2 protection. In T1, the sugar content remained relatively stable. This is likely due to the use of sulphur dioxide (SO_2), which is commonly used in winemaking and food preservation for its antimicrobial and antioxidant properties. Cold storage also found to be slowed down the metabolic processes, including sugar conversion. The Brix level in T1 decreased slightly from 17.5 to 16.5. This suggested a low level of reduction in sugar content, which related to the stable glucose and fructose levels observed. In T2, the sugar content

decreases significantly ($p < 0.05$). Here, the SO_2 sheet helped to preserve the grapes while the warm storage temperature accelerated the metabolic processes. This resulted faster conversion and consumption of sugars. The Brix level in T2 decreased significantly from 17.5 to 14.8. This indicated a high level of reduction in sugar content, resulted from the accelerated sugar consumption at room temperature. In T3, the sugar content decreases slightly. Without the protective effects of SO_2, the grapes were more susceptible to microbial activity and consumption of the sugars. However, the cold storage managed to slow down these processes. The Brix level in T3 fluctuated and ended up slightly lower than it started (17.5 to 15.66). This suggested some variability in sugar content, possibly due to the lack of SO_2 protection.

Changes in total anthocyanin

Total anthocyanin content in grapes under different storage conditions over a period of 60 days are presented in Figure 6. In control sample, the anthocyanins in fresh grapes degraded the most rapidly without any preservation methods. The lack of SO_2 allowed for enzymatic browning to occur. The anthocyanin content decreased significantly from 212.33 to 190 mg/L ($p < 0.05$) without cold storage to slow down these reactions in control sample. The anthocyanin content remained relatively stable in T1 with only minor decrease observed. This could be attributed to the protective effect of sulphur dioxide (SO_2) (Lichter et al., 2008). It worked by inhibiting the action of polyphenol oxidase, an enzyme that contributed to the browning of fruits and the degradation of anthocyanins (Ahmed et al., 2018). Cold storage further slowed down these enzymatic reactions and the growth of spoilage microorganisms (Elatafi et al., 2023). Therefore, the combination of SO_2 and cold storage found to be the most effective preservation of anthocyanins. The anthocyanin content decreased more significantly compared to cold storage. In T2, the SO_2 provided some protection against enzymatic browning but the higher storage temperature accelerated these reactions. Heat can provide the energy needed for chemical reactions, including those that degrade anthocyanins. Therefore, even with the use of SO_2, the anthocyanin content decreased more significantly up to 205.25 mg/L at room temperature (Elatafi et al., 2023; Muche et al., 2018). In the absence of SO_2, the protective effect against enzymatic browning was lost in T3. Even though cold storage can slow down these reactions, the lack of SO_2 led to a more significant decrease up to 199.22 mg/L ($p < 0.05$) in anthocyanin content. This stated the importance of SO_2 in the preservation of anthocyanins (Ahmed et al., 2018; Lichter et al., 2008).

Changes in total phenols

The phenols content in control samples significantly decreased over time, starting from 2115.1 mg/L and dropped to 1856.25 mg/L as shown in Figure 7. This was due to natural degradation processes. The phenols content remained relatively stable in T1, with a slight decreased from 2115.1 mg/L to 2102.39 mg/L. This suggested the use of SO_2 sheets and cold storage effectively preserve phenols. The use of SO_2 sheets seems to have a preserving effect on the phenols content, especially when combined with cold storage. Similar trend was observed by Antoniewicz et al. (2021) indicated that storage conditions and time affect the antioxidant activity and polyphenol content. The phenols content decreased more significantly in T2 i.e., from 2115.1 mg/L to 1992.56 mg/L ($p < 0.05$), compared to T1. This indicated that temperature may play a role in the preservation of phenols, also observed by Zheng et al. (2021).

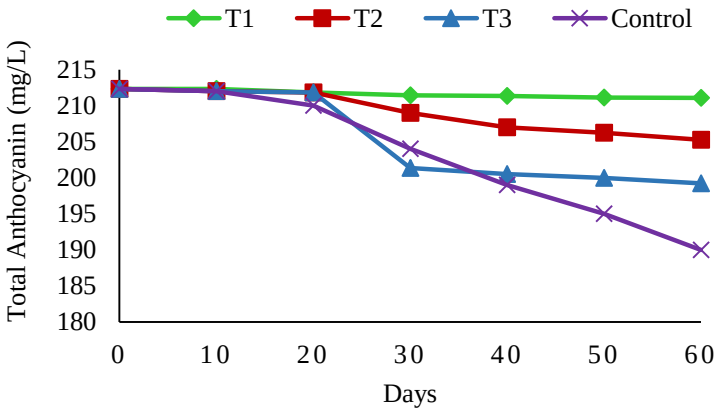

Fig. 6. Change in total anthocyanin in grapes, stored in different conditions.

(T1 = SO_2 sheet with cold storage grapes, T2 = SO_2 sheet at room temperature grapes, T3 = Without SO_2 sheet at cold storage grapes, Control = Without SO_2 sheet at room temperature grapes).

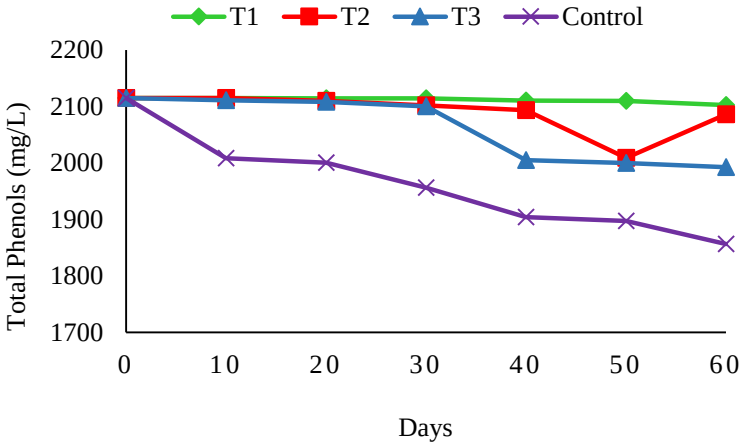

Fig. 7. Change in total phenols in grapes, stored in different conditions.

(T1 = SO_2 sheet with cold storage grapes, T2 = SO_2 sheet at room temperature grapes, T3 = Without SO_2 sheet at cold storage grapes, Control = Without SO_2 sheet at room temperature grapes).

Decay % and weight loss % of grapes

Controlled samples were presumably stored without any special conditions or treatments. They experienced the highest decay and weight loss percentages, reaching 78% decay and 33.58% weight loss by the end of the period as shown in Figures 8 and 9. T1 grapes were stored in cold storage with an SO_2 sheet. The decay and weight loss percentages gradually increased over time, reaching 10.78% decay and 15% weight loss by the end of the 60-day period. T2 grapes were stored at room temperature with an SO_2 sheet. The decay and weight loss percentages were slightly higher than the cold storage grapes, reaching 10.9% decay and 15.58% weight loss by the end of the period. T3 grapes were stored in cold storage without an SO_2 sheet. The decay and weight loss percentages were higher than the grapes stored with an SO_2 sheet, reaching 11.15% decay and 16.2% weight loss by the end of the period.

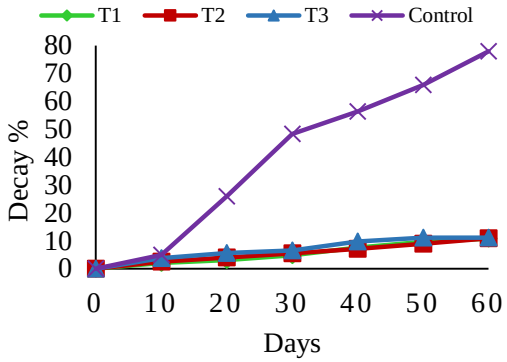

Fig. 8. Decay % of grapes in different conditions. (T1 = SO_2 sheet with cold storage grapes, T2 = SO_2 sheet at room temperature grapes, T3 = Without SO_2 sheet at cold storage grapes, Control = Without SO_2 sheet at room temperature grapes).

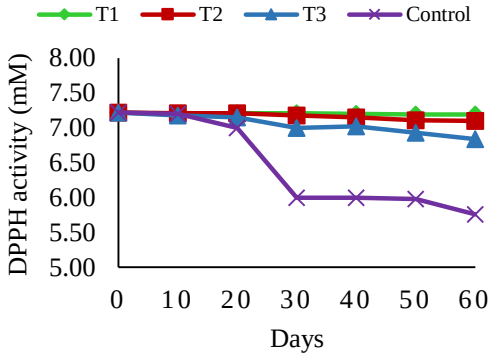

Fig. 10. Antioxidant activity of grapes in different conditions. (T1 = SO_2 sheet with cold storage grapes, T2 = SO_2 sheet at room temperature grapes, T3 = Without SO_2 sheet at cold storage grapes, Control = Without SO_2 sheet at room temperature grapes).

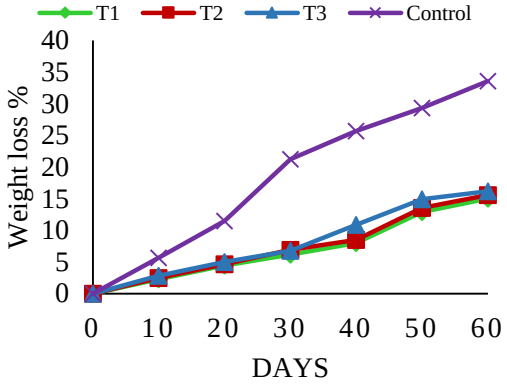

Fig. 9. Weight loss % of grapes in different conditions. (T1 = SO_2 sheet with cold storage grapes, T2 = SO_2 sheet at room temperature grapes, T3 = Without SO_2 sheet at cold storage grapes, Control = Without SO_2 sheet at room temperature grapes).

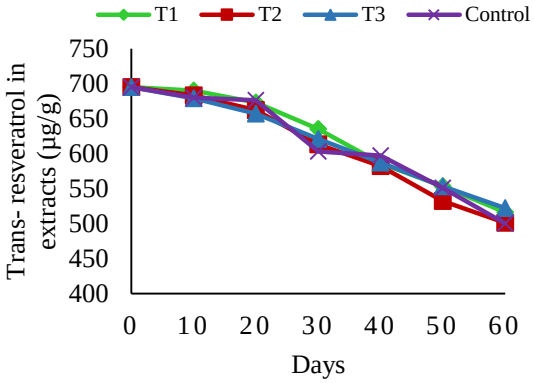

Fig. 11. Trans-resveratrol concentration of grapes in different conditions. (T1 = SO_2 sheet with cold storage grapes, T2 = SO_2 sheet at room temperature grapes, T3 = Without SO_2 sheet at cold storage grapes, Control = Without SO_2 sheet at room temperature grapes).

Antioxidant activity of grapes

The antioxidant activity started at 7.22 mM and decreased to 5.76 mM, stated the highly significant decrease among all conditions as shown in Figure 10. This suggested that without any preservation methods (SO_2 sheet or cold storage), the antioxidant activity of the grapes decreased the most in control sample. The antioxidant activity remained relatively stable in T1 i.e., from 7.19 to 7.22 mM. This suggested that the use of SO_2 sheets in combination with cold storage effectively preserved the antioxidant activity of the grapes. The antioxidant activity started at 7.22 mM and decreased to 7.1 mM in T2. This indicates that while the SO_2 sheet provides some preservation of antioxidant activity, the lack of cold storage led to a slight decreased over time. The antioxidant activity was initially found to be 7.22 mM and decreased more significantly to 6.84 mM ($p < 0.05$) in T3. This suggested that while cold storage alone can preserve some antioxidant activity, the absence of an SO_2 sheet led to a

more noticeable decrease. The antioxidant activity in grapes was primarily due to their phenolic compounds (Nile et al., 2013; Bunea et al., 2012). Higher number of phenolic compounds in T1 contributed to higher antioxidant activity in the storage condition T1 compared to other. The preservation of these compounds can be influenced by storage conditions. SO_2 is known to have preservative qualities and can help maintain the quality of stored grapes. Cold storage can also maintain high antioxidant activity and delay senescence in fruits.

Trans-resveratrol concentration of grapes

The concentration of trans-resveratrol in T1 starts at 695 µg/g and gradually decreased to 516 µg/g over 60 days. This suggested that the synergy of an SO_2 sheet and cold storage reduced the degradation of trans-resveratrol as shown in Figure 11. In T2, the concentration decreased to 501 µg/g over the same period. This indicated that room temperature storage, even with an SO_2 sheet, resulted in a rapid degradation rate of trans-resveratrol compared to cold storage. In T3, the concentration decreased to 522 µg/g over 60 days. This suggested that cold storage without an SO_2 sheet is slightly less effective at preserving trans-resveratrol compared to synergy with an SO_2 sheet. In control samples, the concentration decreased to 500 µg/g over 60 days. This was found to be the highest degradation rate among the four conditions, stated that room temperature without any preservation methods is the least effective at maintaining the concentration of trans-resveratrol.

CONCLUSION

This research investigated the effects of different storage conditions on the quality of grapes. The findings demonstrated that grapes stored with a combination of SO_2 sheets and cold storage (T1) maintained the best overall quality. This treatment resulted in the slowest decline in malic acid content, total soluble solids (TSS), glucose, fructose, trans-resveratrol, decay %, weight loss % and total anthocyanin content, while also exhibited the least significant decrease in total phenols and antioxidant activity. Grapes stored at room temperature without any preservation (control) showed the most significant decline in all measured quality parameters. This highlighted the importance of proper storage techniques to maintain grape quality. The study also found that SO_2 sheets provided some preservative benefits even at room temperature (T2), but these benefits were not as pronounced as when combined with cold storage. Cold storage alone (T3) also offered some preservation compared to room temperature storage, but again, the results were not as effective as the combined SO_2 and cold storage treatment. The research suggested that grape growers and retailers can significantly improve grape quality and shelf life by employing a combination of SO_2 fumigation and cold storage during post-harvest handling.

Conflict of interest

The authors have no conflict of interest to report.

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