The effects of constant concentrations of sulfur dioxide on the quality evolution of postharvest table grapes

XIAOYU CHEN – WEISONG MU – SIEKEL PETER – XIAOSHUAN ZHANG – ZHIQIANG ZHU

Summary

In this work, 10 treatments of Kyoho grapes were preserved to analyse the effects of constant concentrations of sulfur dioxide (SO_2) and temperature on the quality evolution of table grapes to provide references for the preservation technology improvement and the shelf life prediction. With the increase in SO_2 concentration and the decrease in temperature, the peak time of soluble solids content was delayed or the rising stage disappeared. The addition of SO_2 elevated the apparent activation energy of brown stain, which made the rate of the increase in brown stain more sensitive to temperature. The addition of SO_2 showed an effect of inhibition and delay, together with low temperature, on the accumulation of saccharides in table grapes in the early storage. The change in pH value in an environmental range, which is a common situation in actual cold-chain logistics, showed a trend of monotone decrease and could be described by using a unified model. The evolution of pH value and brown stain could be used as reference indices for the shelf life prediction of table grapes in corresponding surroundings.

Keywords

grape; quality; sulfur dioxide

Table grapes enjoy great popularity in the world and occupy an important position in world fruits trade. As a kind of berry fruits, table grapes are perishable. Studying the quality evolution of table grapes is the basis for shelf life prediction research, which would be meaningful for the improvement of post-harvest logistics management of table grapes. The application of SO_2 is the most commonly used fresh-keeping technique for table grapes in the world. Therefore, taking the factor of SO_2 into consideration is necessary in the related research. However, in related studies, SO_2 was commonly obtained from SO_2 controlled-release pads [1, 2], from which the concentration of SO_2 was not certain during storage experiments. Currently, studies related to post-harvest quality evolution of table grapes are commonly qualitative and mainly evaluate the effect of various fresh-keeping technologies on the quality evolution of table grapes [3–8] with just few studies that comprise quantitative modelling of the quality evolution. For example, DENG et al. [9] modelled the moisture loss and firmness of table grapes during post-harvest storage considering the effect of temperature.

Shelf life prediction of fruit is conducive to reducing the loss in post-harvest logistics. It is generally based on quantitative description of the evolution of representative quality indices of the fruit and the effects of environmental factors [10–13]. As an indicator for the shelf life prediction, the evolution of the fruit quality index should be monotonic. However, many important quality indices of fruit could show an increase followed by decrease, which is beacuse of post-harvest ripening or because of other factors. For example, the evolution of soluble solids content (SSC) in post-harvest peach [14], plum [15], mango [16], apri-

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cot [17], and muskmelon [18] showed a trend of increase followed by decrease during post-harvest storage. The evolution of vitamin C in papaya [19] and mango [20] showed a trend of decrease after accumulation in the early storage period. Similarly, the evolution of pH value also showed a trend of increase followed by decrease in post-harvest mangoes [21]. In berry fruits, for the purple passion fruit in post-harvest storage, the evolution of SSC and total carotenoids could show a trend of increase followed by decrease, similar to the antioxidative substances of phenolics and vitamin C [22]. The pH value evolution of strawberry also showed a trend of increase followed by decrease [23]. However, only few reports are available about table grapes.

Study about the quality evolution of table grapes under constant concentrations of SO_2 would be meaningful for improving the preservation technology and could be a valuable reference for the shelf life prediction of table grapes in different environments.

MATERIALS AND METHODS

Table grape samples

The Kyoho grapes used as samples in this study were picked from a vineyard in Hebei province, China. They were transported on the same day to the laboratory for pre-cooling at 0 °C. Injured fruits were clipped off and approximately 10 bunches of grapes were packaged in each box. Ten treatments with different temperature or SO_2 concentration were prepared as shown in Tab. 1. Three boxes of grapes were prepared for each treatment. The concentration of SO_2 was maintained by using an electromagnetic valve controlled by a SO_2 concentration monitoring sensor. The electromagnetic valve was connected with a SO_2 tank by polytetrafluoroethylene tube. The sensor was put into the box to monitor the SO_2 concentration in the storage environment of the table grapes and, in case of a decrease in concentration, the sensor would control the electromagnetic valve open so that the SO_2 gas would be supplied automatically. According to the storage duration of the table grapes in different treatments, interval sampling detections were conducted for every treatment of table grapes during storage. The monitoring quality indices included SSC, pH value and brown stain.

Soluble solids content, pH value and brown stain determination

SSC was determined from the juice by using a handheld digital refractometer (Atago PAL-1; Atago, Tokyo, Japan). The pH value was measured from the juice by using a pH meter (PHS-3C; Jingke, Shanghai, China). The brown stain was determined by observing the branches of the table grapes according to a grading of 6 levels: 0 – fresh light green, 1 – green, 2 – dark green, 3 – green to light brown, 4 – brown, 5 – brown to dark grey and dried [24].

Tab. 1. Treatments with different temperature or SO_2 concentration.

Treatments	Temperature [°C]	SO_2 [$cm^3 \cdot m^{-3}$]
A1		0
A2	0	10
A3		20
B1		0
B2	10	10
B3		20
C1		0
C2	20	10
C3		20
D1	25	0

Statistical analysis

The evolution data of quality indices were fitted with the zero-order reaction kinetics model and the first-order reaction kinetics model, which could be described as follows:

$$Q = Q_0 - kt \tag{1}$$

$$Q = Q_0 \exp(-kt) \tag{2}$$

where Q is quality index value at time t, Q_0 is initial value of Q, k is change rate and t is time.

To describe the effect of temperature on the quality evolution of table grapes, Arrhenius equation was used, which could be described as:

$$k = A \exp(-E_\alpha/RT) \tag{3}$$

where A is pre-exponential factor, E_α is reaction activation energy, R is gas constant and T is temperature.

RESULTS AND DISCUSSION

Evaluationsof the quality indices of table grapes

The evolution of SSC (Fig. 1) in table grapes showed a trend of increase followed by decrease at temperatures higher than 10 °C. The peak time at 10 °C was later than at 20 °C or 25 °C, while no

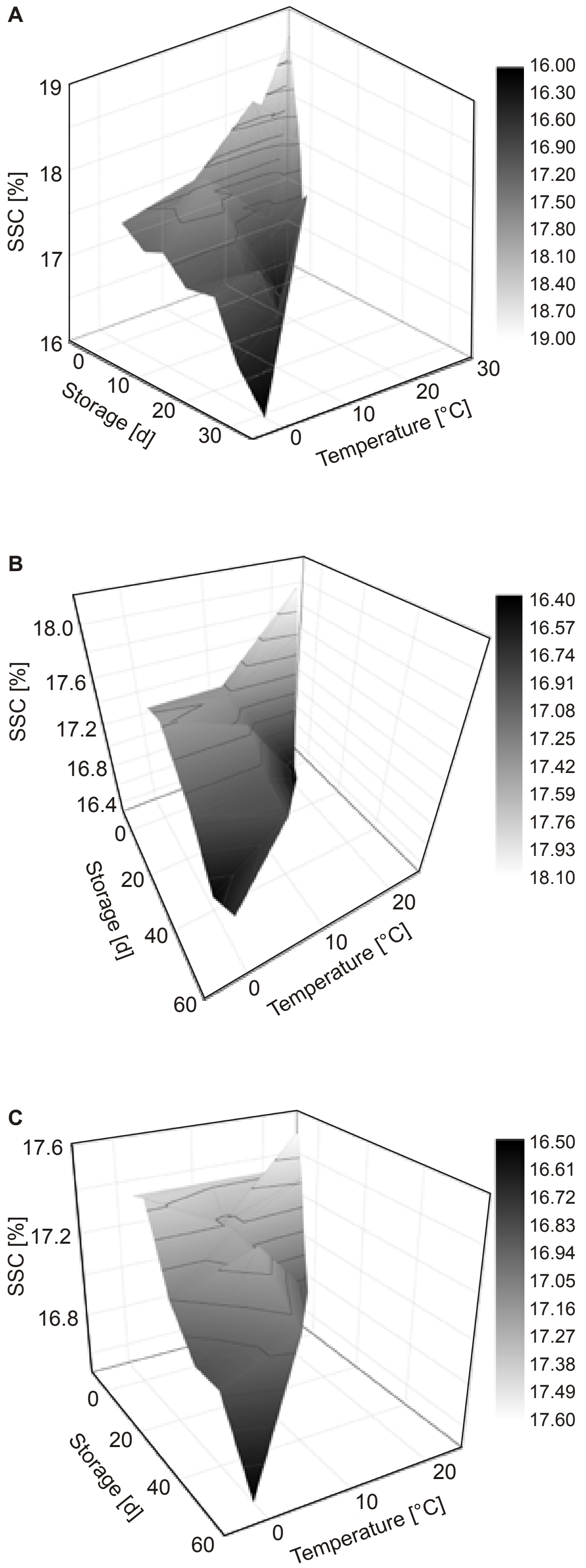

Fig. 1. Evolution of soluble solid content in table grapes under the influence of temperature and the different concentrations of SO_2.

SSC – soluble solid content. A – evolution of SSC in table grapes at different temperatures (with no application of SO_2), B – evolution of SSC in table grapes under 10 $cm^3 \cdot m^{-3}$ SO_2, C – evolution of SSC in table grapes under 20 $cm^3 \cdot m^{-3}$ SO_2.

rising stage in SSC evolution at 0 °C was observed. Similarly, the evolution of pH value (Fig. 2) showed a trend of increase followed by decrease at 10 °C, 20 °C and 25 °C, and the peak time at 10 °C was later than at 20 °C or 25 °C. There was not rising stage in the evolution of the pH value at 0 °C.

Similar situation was also observed for purple passion fruit and atemoya [22, 25], which are two other kinds of berry fruits. According to the report of Pongener et al. [22], the evolution of SSC in pos-tharvest purple passion fruit, which was stored at about 20 °C, showed a trend of increase followed by decrease, and the peak times of 10–20 days were observed, according to the mature stage at harvest time. The pH value decreased along with the decay process of ripened table grapes, which was similar to the situations in strawberry and purple passion fruit [22, 23]. Villa-Rojas et al. [23] reported that the maximum of pH value of the strawberry stored at about 3 °C appeared on the 3rd day of storage, and then the pH value began to decrease.

In our experiments, the evolution of SSC could be described by using the first-order reaction model in both increasing and decreasing stages, as shown in Tab. 2 and Tab. 3. The effects of temperature conformed to Arrhenius equation (Tab. 4). The evolution of pH value showed a trend of increase followed by decrease at temperatures higher than 10 °C. The maximum rates of increase and decrease both occurred at 20 °C. The effects of temperature on the evolution of pH value did not conform to Arrhenius equation.

The evolution of brown stain (Fig. 3) and the effects of temperature could be described by using the zero-order reaction model and Arrhenius equation (Tab. 2, Tab. 4). The quality indices of SSC and pH value of table grapes showed a non-monotonic evolution trend and low temperature showed the effects of delay and inhibition according to the delayed peak time, disappearance of the rising stage, and the lower change rates of quality indices.

Influence of SO_2 at different concentrations and temperatures

At 20 °C, the peak time of SSC was delayed with the increase of SO_2 concentration, while the peak value decreased. At concentrations of 0, 10 and 20 $cm^3 \cdot m^{-3}$ SO_2 (the gas concentration unit means the volume content of SO_2 measured by cubic centimetres in 1 m^3 of space), the peak value was 18.3%, 18.1% and 17.6%, and appeared after 1, 4 and 6 days of storage, respectively. Under different concentrations of SO_2, the evolution of SSC conformed to first-order reaction kinetics model, and the change rate decreased with the increase in SO_2 concentration in both increasing and decreasing stages (Tab. 2, Tab. 3). The addition of SO_2 showed effects of inhibition and delay on the accumulation or consumption of SSC in post-harvest table grapes. The effects were enhanced with the increase in SO_2 concentration within a range of 0–20 $cm^3 \cdot m^{-3}$. At 10 °C, the concentrations of both 10 $cm^3 \cdot m^{-3}$ and 20 $cm^3 \cdot m^{-3}$ SO_2 made the increasing stage of SSC disappear and the change rate to slow down. However, the difference of the effect between 10 $cm^3 \cdot m^{-3}$ and 20 $cm^3 \cdot m^{-3}$ SO_2 was not obvious. At 0 °C, SO_2 at both 10 $cm^3 \cdot m^{-3}$ and 20 $cm^3 \cdot m^{-3}$ slowed down the decrease in SSC in table grapes, which indicated that the application of SO_2 in cold storage was beneficious for quality preservation of table grapes.

The effects of SO_2 on pH were similar to those on SSC (Fig. 2). At 20 °C, SO_2 at concentrations of both 10 $cm^3 \cdot m^{-3}$ and 20 $cm^3 \cdot m^{-3}$ delayed the

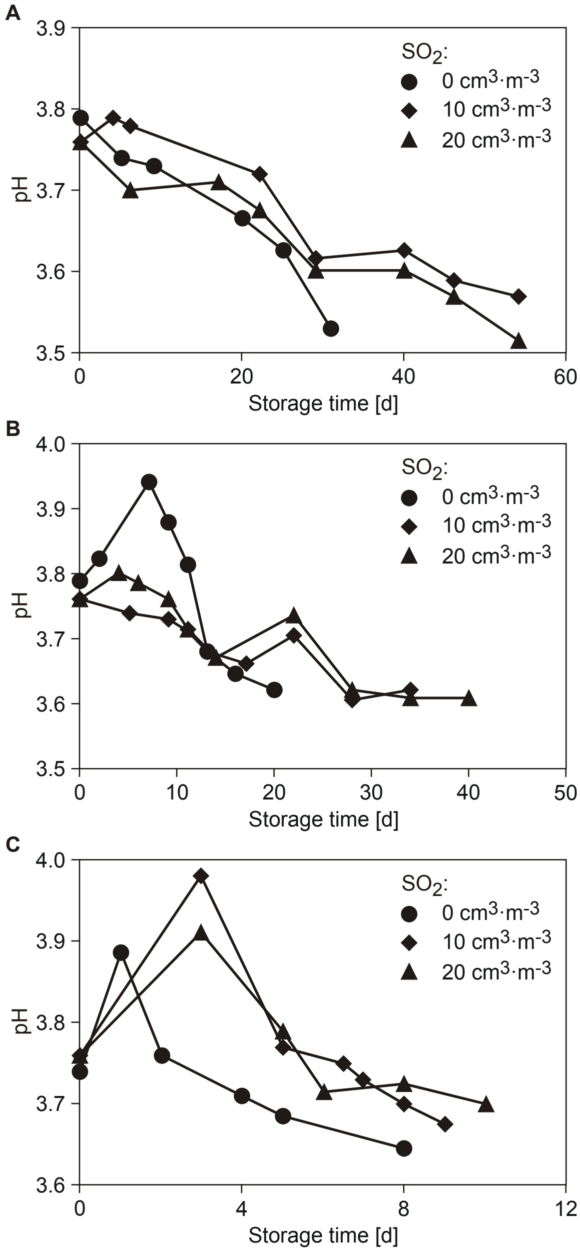

Fig. 2. Evolution of pH value in table grapes at different temperatures and under different concentrations of SO_2.

A – 0 °C, B – 10 °C, C – 20 °C.

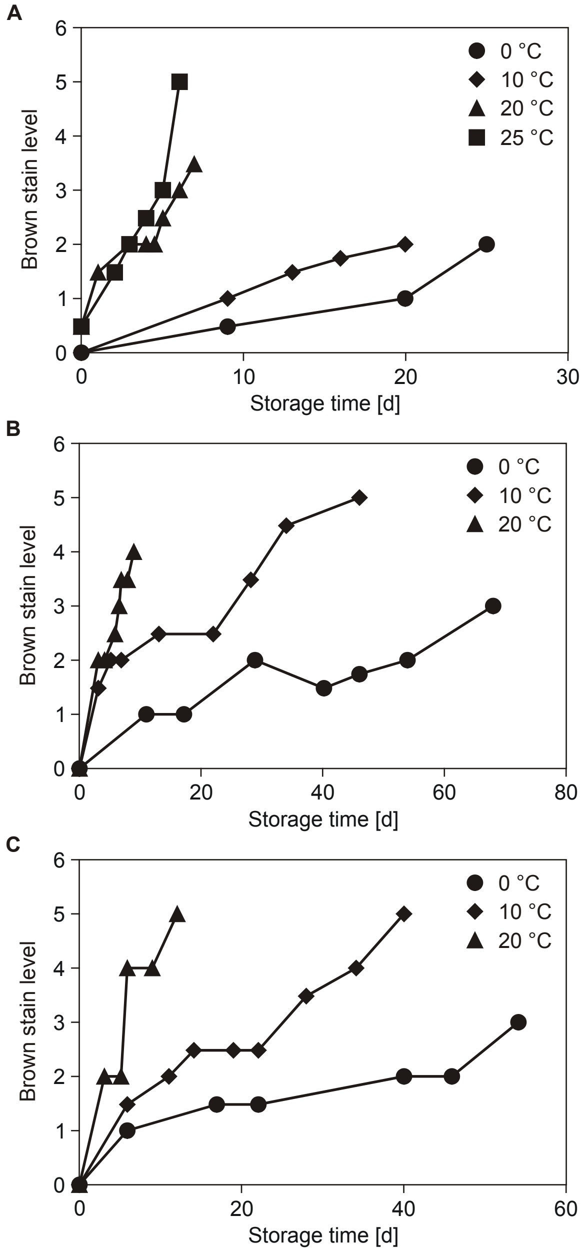

Fig. 3. Evolution of brown stain of table grapes under different concentrations of SO_2 and at different temperatures.

A – SO_2 0 $cm^3 \cdot m^{-3}$, B – SO_2 10 $cm^3 \cdot m^{-3}$, C – SO_2 20 $cm^3 \cdot m^{-3}$.

Tab. 2. Decrease rates of quality indices obtained with chemical kinetic models and goodness-of-fit.

Indexes		Soluble solids content		pH		Brown stain	
Models		First-order reaction model		First-order reaction model		Zero-order reaction model	
Fitting		*k*	R^2	*k*	R^2	*k*	R^2
SO_2 0 $cm^3 \cdot m^{-3}$	0 °C	0.002	0.818	0.002	0.949	0.071	0.893
	10 °C	0.004	0.906	0.007	0.888	0.103	0.988
	20 °C	0.023	0.909	0.008	0.811	0.368	0.919
	25 °C	0.027	0.914	0.007	0.798	0.671	0.898
SO_2 10 $cm^3 \cdot m^{-3}$	0 °C	0.001	0.775	0.001	0.905	0.036	0.850
	10 °C	0.0008	0.919	0.001	0.821	0.091	0.892
	20 °C	0.018	0.875	0.012	0.873	0.421	0.957
SO_2 20 $cm^3 \cdot m^{-3}$	0 °C	0.001	0.944	0.001	0.932	0.042	0.873
	10 °C	0.0005	0.864	0.001	0.799	0.108	0.946
	20 °C	0.007	0.994	0.007	0.746	0.406	0.887

k – change rate, R^2 – coefficient of determination.

Tab. 3. Increase rates of quality indices obtained with chemical kinetic models and goodness-of-fit.

Indexes		Soluble solids content		pH	
Models		First-order reaction model		First-order reaction model	
Fitting		*k*	R^2	*k*	R^2
SO_2 0 $cm^3 \cdot m^{-3}$	0 °C	–	–	–	–
	10 °C	0.004	0.850	0.006	0.996
	20 °C	0.047	1.000	0.038	1.000
	25 °C	0.041	0.968	0.019	0.999
SO_2 10 $cm^3 \cdot m^{-3}$	0 °C	–	–	–	–
	10 °C	–	–	–	–
	20 °C	0.010	1.000	0.019	1.000
SO_2 20 $cm^3 \cdot m^{-3}$	0 °C	–	–	–	–
	10 °C	–	–	–	–
	20 °C	0.002	1.000	0.013	1.000

k – change rate, R^2 – coefficient of determination.

peak time of pH value and, at 10 °C, they made the increasing stage of pH value disappear, while slowing down the change rates. At 0 °C, the addition of SO_2 slowed down the decrease rate of pH value. At 0 °C and 10 °C with SO_2 at 10 $cm^3 \cdot m^{-3}$ or 20 $cm^3 \cdot m^{-3}$, the change rates of pH value were the same (Tab. 2).

SO_2 at concentrations of both 10 $cm^3 \cdot m^{-3}$ and 20 $cm^3 \cdot m^{-3}$ elevated the apparent reaction activation energy of brown stain (Tab. 4), which made the rate of brown stain more sensitive to temperature. The situations with different concentrations of SO_2 should be considered respectively in modelling the brown stain of table grapes.

Quality evolution and shelf life prediction

Quality indices of table grapes, such as SSC or pH value, showed a non-monotonic evolution

Tab. 4. Effects of temperature on the quality evolution described by Arrhenius equation and goodness-of-fit.

Index	SO_2 [$cm^3 \cdot m^{-3}$]	Linear regression Arrhenius equation	E_α [$kJ \cdot mol^{-1}$]	*R*
Brown stain	0	$y = -7479.6x + 24.521$	62.185	0.9336
	10	$y = -9854.6x + 32.633$	81.931	0.9759
	20	$y = -9037.8x + 29.846$	75.140	0.986
SSC (increasing stage)	0	$y = -13796.0x + 43.446$	114.699	0.8713
SSC (decreasing stage)	0	$y = -9241.2x + 27.466$	76.831	0.9531

SSC – soluble solids content, E_α – reaction activation energy, *R* – coefficient of determination.

trend during postharvest storage, therefore, the evolution of these quality indices could not be appropriately directly used for the shelf life modelling of table grapes. However, the evolution of pH value in an environmental range of 0–10 °C with 10–20 $cm^3 \cdot m^{-3}$ SO_2 showed a trend of monotone decrease. The effects of both SO_2 concentration and temperature on the change rate were not significant. The evolution of the pH value in this environmental range could be described by using first-order reaction kinetics model (Fig. 4). Therefore, the pH value could be used as a referenced indicator of table grapes' shelf life in this environmental range, which happened to be a common surrounding fluctuating range in actual table grape cold-chain logistics.

Under SO_2 at concentrations of 0, 10, and 20 $cm^3 \cdot m^{-3}$, the evolution of brown stain, which is a major cause of termination of shelf life of table grapes during post-harvest logistics with the application of SO_2, conformed to zero-order reaction kinetics model (Tab. 2). The effects of temperature under different concentrations of SO_2 could be described by using Arrhenius equation (Tab. 4).

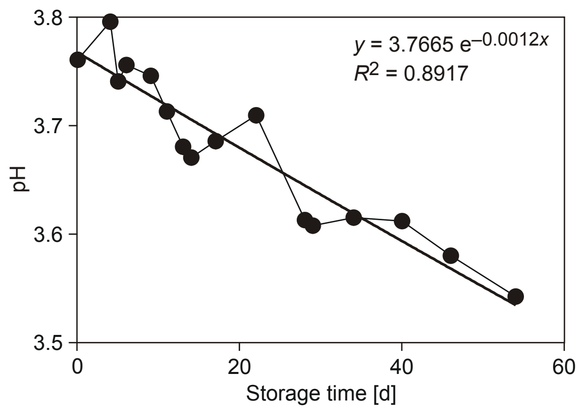

Fig. 4. Evolution of pH value in table grapes in an environmental range of 0–10 °C with 10–20 $cm^3 \cdot m^{-3}$ SO_2.

CONCLUSION

The evolution of SSC of table grapes showed an increasing trend in early storage, and then it decreased with the decay process, together with the pH value. SO_2 at concentrations of both 10 $cm^3 \cdot m^{-3}$ and 20 $cm^3 \cdot m^{-3}$ inhibited and delayed the increase, similarly as the low temperature according to experiments at 0 °C, 10 °C and 20 °C. For the non-monotonic evolution, these indices were not appropriate to be used directly for the shelf life modelling. Furthermore, because of the significant influence of SO_2 on the post-harvest quality evolution of table grapes, the effects of SO_2 concentration are necessary to be considered in modeling the shelf life of table grapes. We found that the evolution of the pH value in an environmental range of 0–10 °C with 10–20 $cm^3 \cdot m^{-3}$ SO_2, as a common environmental range in actual cold-chain logistics, showed a trend of monotone decrease and was not sensitive to temperature or SO_2 concentration. The evolution of pH value in this environmental range could be described by using first-order reaction kinetics model (Fig. 4), which could be used as a referential indicator for the shelf life prediction of table grapes in cold-chain logistics. The evolution of the brown stain, as a major cause for table grapes to terminate their shelf life in post-harvest logistics with the application of SO_2, could be described by using zero-order reaction kinetics model under 0, 10, and 20 $cm^3 \cdot m^{-3}$ SO_2. The effects of temperature conformed to Arrhenius equation, which could be used as a referential indicator for the shelf life prediction of taable grapes under corresponding concentrations of SO_2. Additionally, SO_2 at concentrations of both 10 $cm^3 \cdot m^{-3}$ and 20 $cm^3 \cdot m^{-3}$ elevated the apparent reaction activation energy of brown stain, which made the rate of brown stain changes more sensitive to temperature.

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REFERENCES

1. Guzev, L. – Danshin, A. – Zahavi, T. – Ovadia, A. – Lichter, A.: The effects of cold storage of table grapes, sulphur dioxide and ethanol on species of black *Aspergillus* producing ochratoxin A. International Journal of Food Science and Technology, *43*, 2008, pp. 1187–1194. DOI: 10.1111/j.1365-2621.2007.01589.x.
2. Mustonen, H. M.: The efficacy of a range of sulfur dioxide generating pads against *Botrytis cinerea* infection and on out-turn quality of Calmeria table grapes. Journal of Experimental Agriculture, *32*, 1992, pp. 389–393. DOI: 10.1071/EA9920389.
3. Gabler, F. M. – Mercier, J. – Jimenez, J. I. – Smilanick, J. L.: Integration of continuous biofumigation with *Muscodor albus* with pre-cooling fumigation with ozone or sulfur dioxide to control postharvest gray mold of table grapes. Postharvest Biology and Technology, *55*, 2010, pp. 78–84. DOI: 10.1016/j.postharvbio.2009.07.012.
4. Lu, S. – Yang, X. – Li, X. – Shen, L. – Ma, H.: Effect of sulfur dioxide treatment on storage quality and SO_2 residue of Victoria grape. Advanced Materials

Research, *798–799*, 2013, pp. 1033–1036. DOI: 10.4028/www.scientific.net/AMR.798-799.1033.
5. Morris, J. R. – Oswald, O. L. – Main, G. L. – Moore, J. N. – Clark, J. R.: Storage of new seedless grape cultivar with sulfur dioxide generators. American Journal of Enology and Viticulture, *43*, 1992, pp. 230–232. ISSN: 0002-9254. <http://www.ajevonline.org/content/43/3/230.abstract>
6. Xu, W. – Li, D. – Fu, Y. – Liu, Z. – Wang, Y. – Yu, X. – Shang, W.: Extending the shelf life of Victoria table grapes by high permeability and fungicide packaging at room temperature. Packaging Technology and Science, *26*, 2013, pp. 43–50. DOI: 10.1002/pts.2002.
7. Franck, J. – Latorre, B. A. – Torres, R. – Zoffoh, J. P.: The effect of preharvest fungicide and postharvest sulfur dioxide use on postharvest decay of table grapes caused by *Penicillium expansum*. Postharvest Biology and Technology, *37*, 2005, pp. 20–30. DOI: 10.1016/j.postharvbio.2005.02.011.
8. Harindra Champa, W. A. – Gill, M. I. S. – Mahajan, B. V. C. – Arora, N. K.: Postharvest treatment of polyamines maintains quality and extends shelf-life of table grapes (*Vitis vinifera* L.) cv. Flame Seedless. Postharvest Biology and Technology, *91*, 2014, pp. 57–63. DOI: 10.1016/j.postharvbio.2013.12.014.
9. Deng, Y. – Wu, Y. – Li, Y.: Effects of high O_2 levels on post-harvest quality and shelf life of table grapes during long-term storage. European Food Research and Technology, *221*, 2005, pp. 392–397. DOI: 10.1007/s00217-005-1186-4.
10. Torrieri, E. – Russo, F. – Di Monaco, R. – Cavella, S. – Villani, F. – Masi, F.: Shelf life prediction of fresh italian pork sausage modified atmosphere packed. Food Science and Technology International, *17*, 2011, pp. 223–232. DOI: 10.1177/1082013210382328.
11. Tsironi, T. – Stamatiou, A. – Giannoglou, M. – Velliou, E. – Taoukis, P. S.: Predictive modelling and selection of time temperature integrators for monitoring the shelf life of modified atmosphere packed gilthead seabream fillets. LWT – Food Science and Technology, *44*, 2011, pp. 1156–1163. DOI: 10.1016/j.lwt.2010.10.016.
12. Tang, X. – Sun, X. – Wu, V. C. H. – Xie, J. – Pan, Y. – Zhao, Y. – Malakar, P. K.: Predicting shelf-life of chilled pork sold in China. Food Control, *32*, 2013, pp. 334–340. DOI: 10.1016/j.foodcont.2012.12.010.
13. Hu, Y. – Liu, C. – Hao, Q. – Zhang, Q. – He, Y.: Building kinetic models for determining vitamin C content in fresh jujube and predicting its shelf life based on near-infrared spectroscopy. Sensors, *13*, 2013, pp. 15673–15681. DOI: 10.3390/s131115673.
14. Brandelli, A – Lopes, C. H. G. L.: Polyphenoloxidase activity, browning potential and phenolic content of peaches during postharvest ripening. Journal of Food Biochemistry, *29*, 2005, pp. 624–637. DOI: 10.1111/j.1745-4514.2005.00026.x.
15. Singh, S. P. – Singh, Z. – Swinny, E. E.: Postharvest nitric oxide fumigation delays fruit ripening and alleviates chilling injury during cold storage of Japanese plums (*Prunus salicina* Lindell). Postharvest Biology and Technology, *53*, 2009, pp. 101–108. DOI: 10.1016/j.postharvbio.2009.04.007.
16. Vasquez-Caicedo, A. L. – Heller, A. – Neidhart, S. – Carle, R.: Chromoplast morphology and β-carotene accumulation during postharvest ripening of mango cv. 'Tommy Atkins'. Journal of Agricultural and Food Chemistry, *54*, 2006, pp. 5769–5776. DOI: 10.1021/jf060747u.
17. Cardarelli, M. – Botondi, R. – Vizovitis, K. – Mencarelli, F.: Effects of exogenous propylene on softening, glycosidase, and pectinmethylesterase activity during postharvest ripening of apricots. Journal of Agricultural and Food Chemistry, *50*, 2002, pp. 1441–1446. DOI: 10.1021/jf011079+.
18. Zhao, X. – Guo, Y. – Huber, D. J. – Lee, J.: Grafting effects on postharvest ripening and quality of 1-methylcyclopropene-treated muskmelon fruit. Scientia Horticulturae, *130*, 2011, pp. 581–587. DOI: 10.1016/j.scientia.2011.08.010.
19. Li, X. – Wu, B. – Guo, Q. – Wang, J. – Zhang, P. – Chen, W.: Effects of nitric oxide on postharvest quality and soluble sugar content in papaya fruit during ripening. Journal of Food Processing and Preservation, *38*, 2014, pp. 591–599. DOI: 10.1111/jfpp.12007.
20. Ibarra-Garza, I. P. – Ramos-Parra, P. A. – Hernandez-Brenes, C. – Jacobo-Velazquez, D. A.: Effects of postharvest ripening on the nutraceutical and physicochemical properties of mango (*Mangifera indica* L. cv Keitt). Postharvest Biology and Technology, *103*, 2015, pp. 45–54. DOI: 10.1016/j.postharvbio.2015.02.014.
21. Castrillo, M. – Bermudez, A.: Post-harvest ripening in wax-coated bocado mango. International Journal of Food Science and Technology *27*, 1992, pp. 457–463. DOI: 10.1111/j.1365-2621.1992.tb01211.x.
22. Pongener, A. – Sagar, V. – Pal, R. K. – Asrey, R. – Sharma, R. R. – Singh, S. K.: Physiological and quality changes during postharvest ripening of purple passion fruit (*Passiflora edulis* Sims). Fruits, *69*, 2014, pp. 19–30. DOI: 10.1051/fruits/2013097.
23. Villa-Rojas, R. – Lopez-Malo, A. – Sosa-Morales, M. E.: Hot water bath treatments assisted by microwave energy to delay postharvest ripening and decay in strawberries (*Fragaria x ananassa*). Journal of the Science of Food and Agriculture, *91*, 2011, pp. 2265–2270. DOI: 10.1002/jsfa.4449.
24. Harvey, J. M. – Harris, C. M. – Hanke, T. A. – Hartsell, P. L.: Sulfur-dioxide fumigation of table grapes – relative sorption of SO_2 by fruit and packages, SO_2 residues, decay, and bleaching. American Journal of Enology and Viticulture, *39*, 1988, pp. 132–136. ISSN: 0002-9254. <http://www.ajevonline.org/content/39/2/132.abstract>
25. Paull, R. E.: Postharvest atemoya fruit splitting during ripening. Postharvest Biology and Technology, *8*, 1996, pp. 329–334. DOI: 10.1016/0925-5214(96)00012-9.

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