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1. Improving traceability and transparency integrating WSN and correlation analysis
2. Monitored in actual aquatic cold chain between Xinjiang and Guangzhou in China.
3. Critical temperatures in table grapes cold chain logistics were determined.
4. Various quality parameters of table grapes were measured at critical temperature.
5. Critical quality parameters of table grapes were determined and measured.

Improving traceability and transparency of table grapes cold chain logistics by integrating WSN and correlation analysis

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Abstract: Effective and efficient measurement and determination of critical quality parameter(s) is the key to improve the traceability and transparency of the table grapes quality as well as the sustainability performance of the table grapes cold chain logistics, and ensure the table grapes quality and safety. This paper is to determine the critical quality parameter(s) in the cold chain logistics through the real time monitoring of the temperature fluctuation implemented with the Wireless Sensor Network (WSN), and the correlation analysis among the various quality parameters. The assessment was conducted through three experiments. Experiment I indicated that the temperature have a large fluctuation from 0℃ to 30℃, and the critical temperatures could be determined as 0 ℃, 5℃,10℃, 15℃, 20℃, 25℃ and 30℃. Experiment II described that the firmness and moisture loss rate, whose Pearson correlation coefficient with the sensory evaluation were all greater than 0.9 at the critical temperatures determined in Experiment I, could be the critical quality parameters. Experiment III illustrated that the critical quality parameters, firmness and moisture loss rate, could be reliable indicators of table grapes quality by the Arrhenius kinetic equation, and results showed that the evaluation model based on the firmness is better to predict the shelf life than that based on the moisture loss rate. The best quality table grapes could be provided for the consumers via the easily and directly tracing and controlling the critical quality parameters in real time in actual cold chain logistics.

Keywords: Quality parameters, Table grapes, Wireless sensor network, Correlation analysis, Cold chain logistics

1. Introduction

Table grapes are popular fruits in the world due to their desirable flavor richness, as well as rich phytonutrients which provide high value of the nutrition and dietary therapy (Jang et al., 1997; Kantsadi et al., 2014; Akaberi & Hosseinzadeh, 2016). To reduce the quality loss and safety hazards of table grapes, and ensure that table grapes are stored in a low temperature environment at all times after harvesting, the table grapes cold chain logistics, which enabled by the use of refrigeration technology (Coulomb, 2008; Jiao, Fu, Mu, McLaughlin, & Xu, 2012; Qi, Xu, Fu, Mira, & Zhang, 2014), was applied. However, the table grapes cold chain logistics was complex with high information discrepancy, the environmental factors in the cold chain logistics, such as the temperature and preservation gas, were mixed together, which affected the quality and safety of table grapes (Feng, Wang, Fu, & Mu, 2014). Therefore, improving the traceability and transparency of table grapes cold chain logistics by determining the quality parameters of table grapes in the cold chain logistics becomes critical (Xiao, Qi, Fu, & Zhang, 2013; Aung & Chang, 2014a).

Various quality parameters, such as the firmness (Balic et al., 2014; Carreno et al., 2015), moisture loss rate (Solyom et al., 2013), total soluble solids (TSS) (Ye, Yue, Yuan, & Li, 2014), titratable acid (TA) (Porep, Walter, Kortekamp, & Carle, 2014) and sensory evaluation (Kim, Oh, Lee, Bin, & Min, 2014), have been reported to evaluate the table grapes quality in the cold chain logistics. However, it is very difficult to determine all these quality parameter(s) in all stages of the cold chain logistics. Therefore, it is important to determine the critical quality parameter(s) and use the critical quality parameter(s) to evaluate the quality of table grapes in the cold chain logistics.

To determine the quality parameters of the table grapes in cold chain logistics, the real time monitoring of the temperature is needed. The temperature in the table grapes cold chain logistics is one of the main factors that directly affect the respiration intensity and the enzyme activity of table grapes (Fu, Yao, Ma, Qi, & Zhang, 2013). Temperature control is therefore crucial in the cold chain logistics of table grapes to reduce deterioration, extend the storage period and maintain the economical value of the produce (Ngcobo, Pathare, Delele, Chen, & Opara, 2013; Kim, Aung, Chang, & Makatsoris, 2015).

One of the best solutions to enable real time monitoring is the implementation of the Wireless Sensor Network (WSN) to collect data in the cold chain logistics. WSN integrates embedded sensor technology, networking and wireless communication technology, as well as distributed processing (Parreno-Marchante, Alvarez-Melcon, Trebar, & Filippin, 2014). WSN detects and records the temperature, relative humidity and the other environment data in the cold chain logistics and sends the collected data to end-users via wireless network. WSN has been widely used in food cold chain logistics (Aung & Chang, 2014b), agriculture (Correa et al., 2014), industry (Xu, Shen, & Wang, 2014), and many other areas. Wireless transmission has many advantages over traditional wire transmission due to its low maintenance cost, higher mobility, better flexibility and fast deployment features which may prove very useful in the table grapes cold chain logistics.

To determine the critical quality parameter(s) among the various quality parameters, the correlation analysis is one of the best ways to be applied to evaluate the relationships among the various quality parameters in table grapes cold chain logistics (Raposo et al., 2015; Lim, Chye, Sulaiman, Suki, & Lee, 2016). The correlation between two quality parameters is more significant when the absolute value of Pearson correlation coefficient between two quality parameters is higher, while there is no correlation between the two quality parameters if the absolute value is approximate to 0 (Ahlgren, Jarneving, & Rousseau, 2003; Wiedermann & Hagmann, 2016).

In consideration of the discussion above, this study contributes to improve the traceability and transparency of the table grapes quality as well as the sustainability performance of the table grapes cold chain logistics by determining the critical quality parameter(s) of table grapes in the cold chain logistics, and ensure the quality and safety of table grapes. The determination of the critical quality parameter(s), which were realized through the real time monitoring of the temperature fluctuation implemented with the WSN, and the correlation analysis among the various quality parameters of table grapes, is presented in more detailed in the following sections. The table grapes quality could be easily and directly traced and controlled in real time via the determination results of the critical quality parameters in actual cold chain logistics.

2. Materials and Methods

2.1 WSN nodes

The WSN detects and senses the temperature, relative humidity and the other environment data such as the gas in the cold chain logistics via the WSN nodes, and then sends the sensor data to end-users via wireless network. The WSN nodes are formed by several wireless sensor nodes and an aggregation node. Each wireless sensor node is composed of a microcontroller, a radio frequency front end with the antenna and an environment sensor. The aggregation node consists of the network coordinator and General Packet Radio Service (GPRS) remote transmission module. The CC2530 and CC2591 (Texas Instruments Incorporated, Dallas, Texas, USA) were used to improve receiver sensitivity, increase output power and the transmission distance.

As discussed in above section, the real time monitoring of the temperature is needed to determine the quality parameters of the table grapes in cold chain logistics. Therefore, the temperature environment sensor was applied in this study. The physical implementation of the wireless sensor node hardware is demonstrated in Figure 1. The temperature, whose optimum value is about 0°C in table grapes cold chain logistics (Xiao, Qi, Fu, & Zhang, 2013), was sensed by SHT11 sensor (Sensirion Incorporated, Staefa, Zurich, Switzerland) which was operated in the temperature range between -40°C and +123.8°C, with an accuracy of ±0.5°C. The wireless sensor nodes were supplied with the 3.7V 3600mAh lithium battery and the aggregation node was supplied with the 5V direct current power.

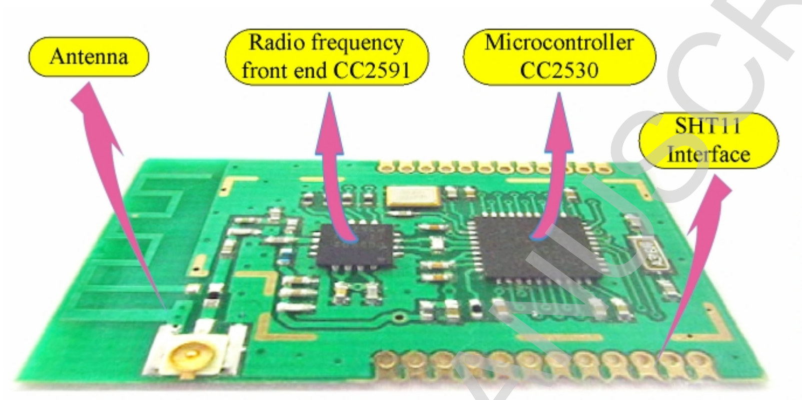

Fig. 1 Physical implementation of the sensor node hardware

2.2 Quality parameters

Five initial table grapes quality parameters were followed and examined. The initial table grapes quality parameters include the firmness, moisture loss, TSS, TA and sensory evaluation.

Firmness is an important parameter used to assess the table grapes freshness and softening degree of the berries (Balic et al., 2014; Xiao, Wang, Zhang, Chen, & Li, 2015). The table grapes firmness was assessed using a handheld durometer (AGY-2, Zhejiang, China) every 12 hours, which measures the force used for compressing a berry by 1 mm, and is expressed as Newton per meter. Ten berries of grapes were used per replicate.

Moisture loss rate was also measured (Ma, Fu, Xu, Trebar, & Zhang, 2016). The total weight of table grapes was measured at the beginning and also for each batch of grapes incubated at a certain temperature by using the electronic analytical balance (EP6102C, Beijing, China). The total weight of the table grapes berries was recorded every 12 hours. The moisture loss was expressed as the percentage loss of the initial total weight. Again ten berries of grapes were randomly selected for each storage temperature for these analyses.

TSS and TA of table grapes were performed (Mirdehghan & Rahimi, 2016). Ten berries of grapes each replicate were crushed by the tissue triturator (JJ-2, Shanghai, China), homogenized, centrifuged at 10,000×g for 15 minutes and the resulted juice was used for the TSS and TA measurements. The TSS was measured using a handheld refractometer (WYT-J, Shanghai, China), and was expressed in mass percentage. TA was measured by titrating a mixture of 10 ml juice and 40 ml deionized water to the endpoint of pH 8.1, and was expressed as mass percentage of tartaric acid.

Sensory evaluation was performed by ten experts who had received special sensory training. The sensory parameters evaluated included the stems dehydration/browning, skin color, fragrance, mesocarp (pulp), sourness/sweetness balance, and juiciness. The assessment scale ranges from 0 to 9 (Freitas, López-Gálvez, Tudela, Gil, & Allende, 2015). 1 means Dislike Extremely; 2 = dislike very much; 3 = dislike moderately; 4 =

dislike slightly; 5 = neither like nor dislike; 6 = like slightly; 7 = like moderately; 8 = like very much; 9 = Like Extremely. Total score is taken as the sum of the average scores given by the experts on the evaluated parameters.

2.3 Correlation analysis

Correlation analysis is related to deal with relationships among variables. The Pearson correlation coefficient is a measure of liner association between two variables (Champa, Gill, Mahajan, & Arora, 2015). The Pearson correlation coefficient R is described as equation (1) (Adler & Parmryd, 2010; Puth, Neuhauser, & Ruxton, 2014).

$$R = \frac{\sum_{i=1}^{n}(X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \overline{X})^2 \sum_{i=1}^{n}(Y_i - \overline{Y})^2}} \tag{1}$$

where n is the sampling number, X_i and Y_i are the i-th measurement value of variable X and Y, $\overline{X}$ and $\overline{Y}$ are the mean value of the variable X and Y.

Absolute values of the Pearson correlation coefficient are always between 0 and 1. The correlation between two variables is more significant once the absolute value of their Pearson correlation coefficient is higher, while there is no correlation between the two variables if the absolute value is approximate to 0 (Tzamalis, Panagiotakos, & Drosinos, 2016). The correlation between sensory evaluation and the other initial table grapes quality parameters could be analyzed using the Pearson correlation coefficient. To determine the critical quality parameter(s) accurately, the correlation of the table grapes quality parameters was considered to be significant when the absolute value of Pearson correlation coefficient was higher than 0.9 (Giacosa et al., 2015).

2.4 Experimental scheme

The Kyoho table grapes (*Vitis vinifera* L. x *V. labrusca* L. cv. Kyoho) were used as the experimental material. Three experiments, illustrated in Figure 2, were conducted.

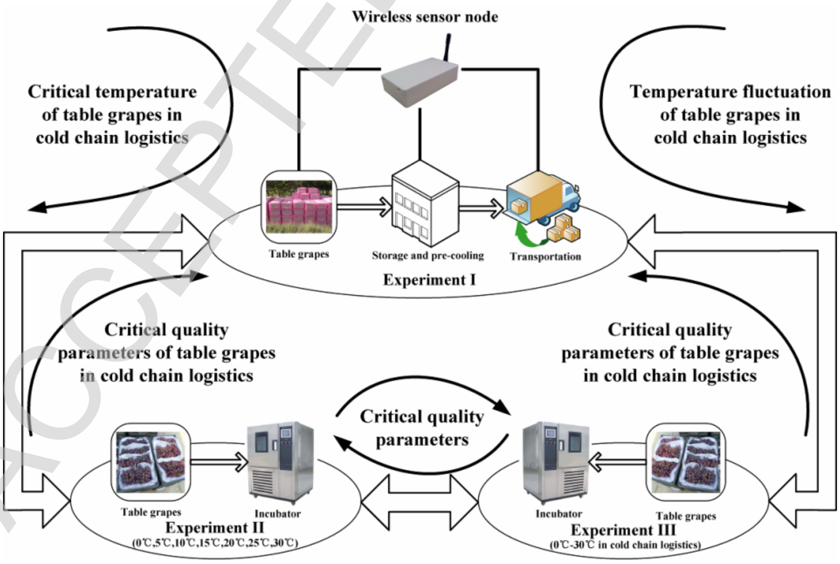

Fig. 2 The diagram of the experiments

- *Experiment I* was performed to monitor the real time temperature fluctuation in the actual table grapes cold chain logistics via the WSN, and determine the critical temperatures of table grapes quality in Experiment II according to the temperature fluctuation range.
- *Experiment II* was performed to measure the initial quality parameters of table grapes under the critical

temperatures condition determined in Experiment I, and determine the critical quality parameter(s) of table grapes in Experiment III by the correlation analysis.

- *Experiment III* was conducted to measure the critical quality parameter(s) of table grapes determined in Experiment II under the temperature fluctuation conditions monitored in Experiment I, and evaluate the table grapes quality in the cold chain logistics.

For Experiment I, table grapes were manually harvested at the complete ripeness stage with uniform sized clusters and without sign of pest damage in a vineyard in Xinjiang, in western China. The table grapes were transported to Guangdong province in south China by using a refrigerated truck at about 0℃. The one-way transportation distance is about 4,300 km, which takes about 20 days. Wireless sensor nodes were placed in the packages with the plastic boxes and the 3.7V 3600mAh lithium battery to monitor the temperature fluctuation and determine the critical temperature(s) of table grapes quality in Experiment II according to the temperature fluctuation range (see Figure 2). There were 36 sensor nodes and an aggregation node. The aggregation node was placed with the 5V direct current power in the control room when the table grapes stored in the cold storage and in the driver cab when in refrigeration transportation. The sampling interval for each sensor node was set to 30 seconds. The length of data sending packet is 5 Bytes, which includes the sensor ID (1 Byte) and the temperature data (4 Bytes).

For Experiment II, table grapes, same variety of table grapes were manually harvested from a greenhouse in Hebei province, China. The table grapes were transported to the laboratory in about two hours and packed in seven cardboard boxes of 5±0.5 kg each, which is followed by a pre-cooling stage in the cold chain storage. The seven boxes of table grapes were stored in the incubators (LHS-150HC, Shanghai, China) under 0℃, 5℃,10℃, 15℃, 20℃, 25℃ and 30℃ critical temperatures determined in Experiment I, respectively, to measure the initial quality parameters of table grapes and determine the critical quality parameter(s) of table grapes in Experiment III by the correlation analysis. All the incubators were set to a relative humidity of 90-93%, to maintain optimum humidity during the experiments (Ngcobo, Pathare, Delele, Chen, & Opara, 2013; Cai et al., 2013). The Experiment II lasted for about 60 days.

For Experiment III, same variety of table grapes were stored in a incubator (LHS-150HC, Shanghai, China) at the fluctuated temperature monitored in Experiment I, ranging from 0℃ to 30℃ and varying as shown in Figure 3, to measure the critical quality parameter(s) of table grapes determined in Experiment II and evaluate the table grapes quality in the cold chain logistics. The incubator was also set to a relative humidity of 90-93%, to maintain optimum humidity during the experiments. The Experiment III lasted for about 20 days.

During the storage period, at various time intervals, ten berries of table grapes were randomly selected from each incubator with different temperature, and analyses were performed in triplicate.

2.5 Statistical analysis

Values of all quality parameters are determined by the average of three replicate assessments. The data regression, fitting, and processing were performed by using Matlab R2013b software (MathWorks Incorporated, Massachusetts Natick, MN, USA). The correlation of the table grapes quality parameters was considered to be significant when the absolute value of Pearson correlation coefficient was higher than 0.9 ($R > 0.9$).

3. Results and Discussion

3.1 Temperature fluctuation analysis

As presented in Experiment I, the temperature fluctuation in the table grapes cold chain logistics is described in Figure 3. The segment AB represents the first stage, during which the table grapes were harvested and prepared for transportation at the farm. The temperature in segment AB, which mainly varied with the ambient temperature, ranged from about 25℃ to 30℃. The segment BC represents the pre-cooling and preservation storage stages. The temperature in pre-cooling stage was reduced rapidly from the ambient temperature to about 0℃ refrigeration temperature. The point C, whose temperature rose to about 10℃ and then rapidly dropped to about 0℃, is the table grapes loading stage. The segment CD is the transportation stage of the table grapes cold chain logistics, during which the temperature remained stable at about 0℃. The segment DE is the table grapes unloading stage. The temperature in segment DE rose rapidly from the 0℃ refrigeration temperature to the ambient temperature ranged from about 25℃ to 30℃.

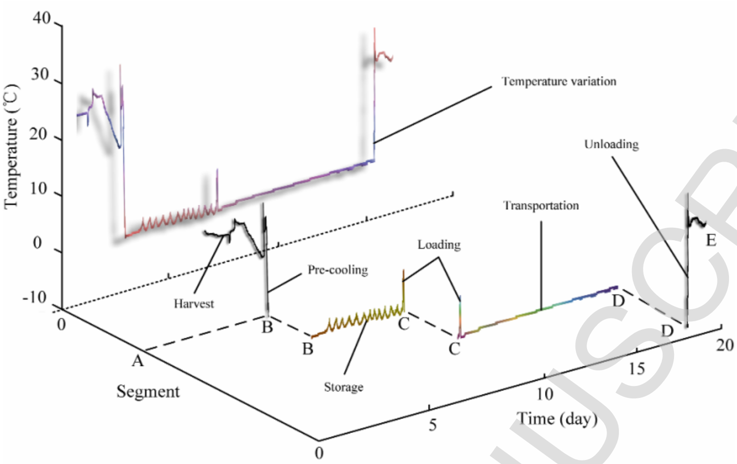

Fig. 3 Temperature fluctuation in the table grape cold chain logistics

The maximum range of temperature fluctuation is about 30℃ when the table grapes were harvested and sold, while the minimum range is about 0℃ when stored and transported. According to the temperature fluctuation range and the stages in the table grapes cold chain logistics mentioned as the above in Figure 3, the critical temperatures of the table grapes quality, could be determined as 0℃, 5℃,10℃, 15℃, 20℃, 25℃ and 30℃, to reflect the table grapes quality as comprehensive as possible (Ma, Fu, Xu, Trebar, & Zhang, 2016).

3.2 Quality parameters analysis

As described in Experiment II, the table grapes firmness evolution at the critical temperatures is illustrated in Figure 4. Firmness decreased as the storage time lasts, irrespective of the storage temperature, but the rate of firmness loss varies significantly at different storage temperature. As expected, the higher the temperature, the faster the firmness loses. A reduction of firmness by 50% occurs after 53 days of storage at 0°C, while at 30°C the same level of reduction is observed in only about 3 days.

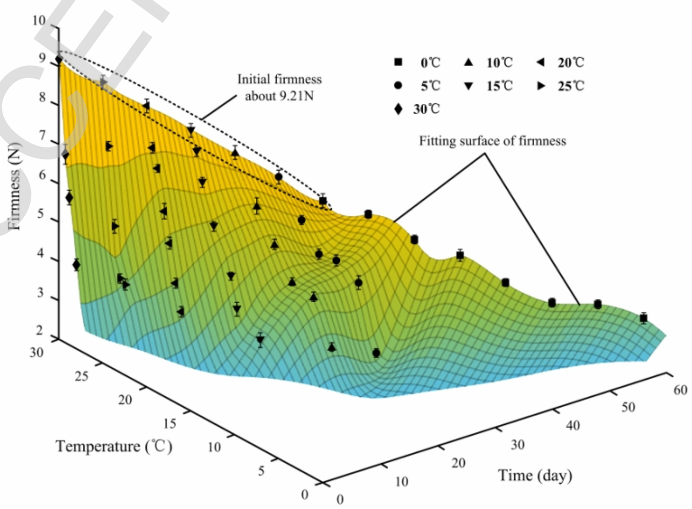

Fig. 4 The table grapes firmness evolution at the critical temperatures

The table grapes moisture loss rate evolution at the critical temperatures is presented in Figure 5. The table grapes moisture loss occurred and varied at critical temperatures, even though the relative humidity was kept constant and at a high value (90-93%).The table grapes moisture loss increased faster as the storage temperature rose. These decaying processes were occurred in 3 days during storage at temperatures of 20℃, 25℃ or 30℃, while at 0℃ the same phenomena only occurred after 50 days of storage.

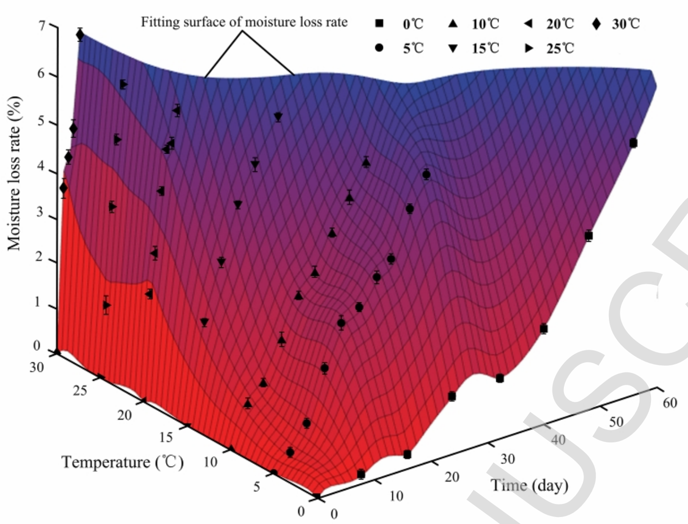

Fig. 5 The table grapes moisture loss rate evolution at the critical temperatures

One of the most critical deteriorations is firmness decreased (or berry softening) (Sato, Yamane, Hirakawa, Otobe, & Yamada, 1997), which is related to biochemical alterations in the cell of table grapes by cell wall degrading enzymes (Brummell, 2006; Carreno et al., 2015). The softening of table grapes in clod chain logistics was occurred primarily due to an increase in enzyme activity as the temperature rose (Giacosa, Marengo, Guidoni, Rolle, & Hunter, 2015).

In addition, taking into account that the moisture content in table grapes is higher than that in many other types of fruits and vegetables (Ngcobo, Delele, Chen, & Opara, 2013), the moisture loss also plays a role in firmness evolution in the table grapes cold chain logistics. Firmness decreased (or berry softening) was found to be directly correlated to fruit moisture loss during storage in previous studies (Solyom et al., 2013; Carreno et al., 2015). This correlation could be also observed immediately by comparing the parameter evolution in our study as shown in Figure 4 and Figure 5.

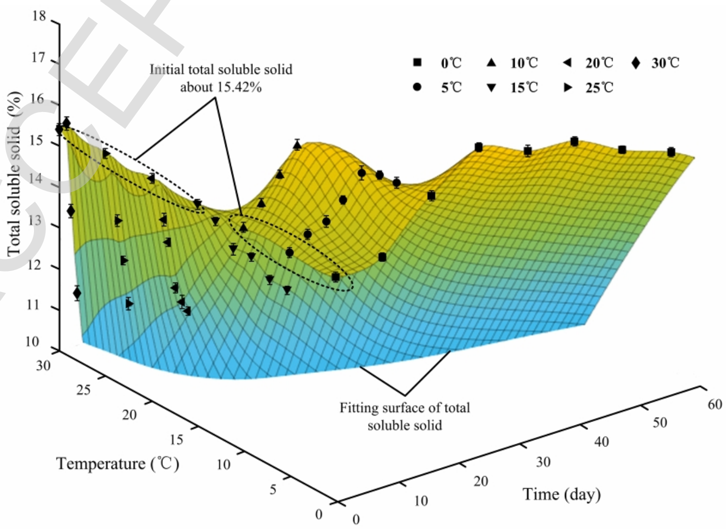

Fig. 6 The table grapes TSS evolution at the critical temperatures

The table grapes TSS evolution at critical temperatures is demonstrated in Figure 6. The TSS content did not show significant differences at 20℃, 25℃, and 30℃ in 6 days, and rose to the maximum level in 9 days and then decreased in the case of 10℃. The results may be affected by the environment and other subjective factors during the measurement (Ye, Yue, Yuan, & Li, 2014).

The table grapes TA evolution at critical temperatures is described in Figure 7. The TA decreased as the temperature increased and the storage time got longer. As expected, the loss of acidity was faster at 20℃, 25℃ and 30℃ critical temperatures, which may be ascribed to the faster metabolic rates in cells as the temperature rose (Sweetman, Sadras, Hancock, Soole, & Ford, 2014).

The table grapes sensory evaluation at critical temperatures is illustrated in Figure 8. The sensory evaluation scores of the table grapes decreased as the storage time, and the scores were lower at the higher temperature.

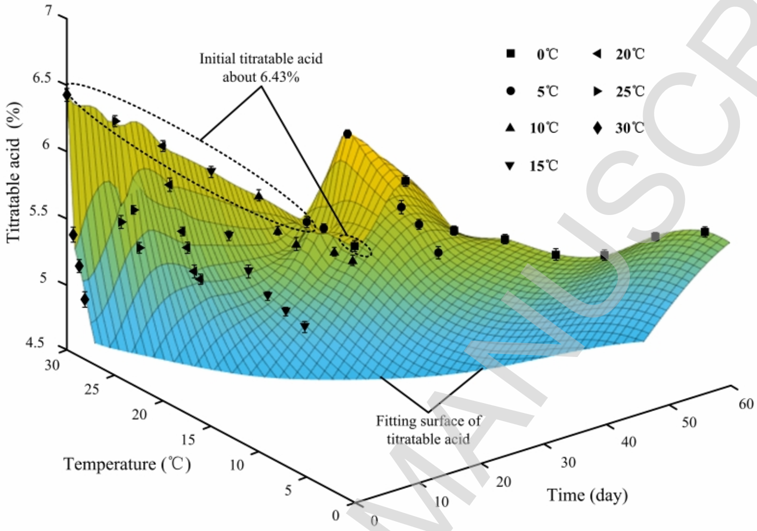

Fig. 7 The table grapes TA evolution at the critical temperatures

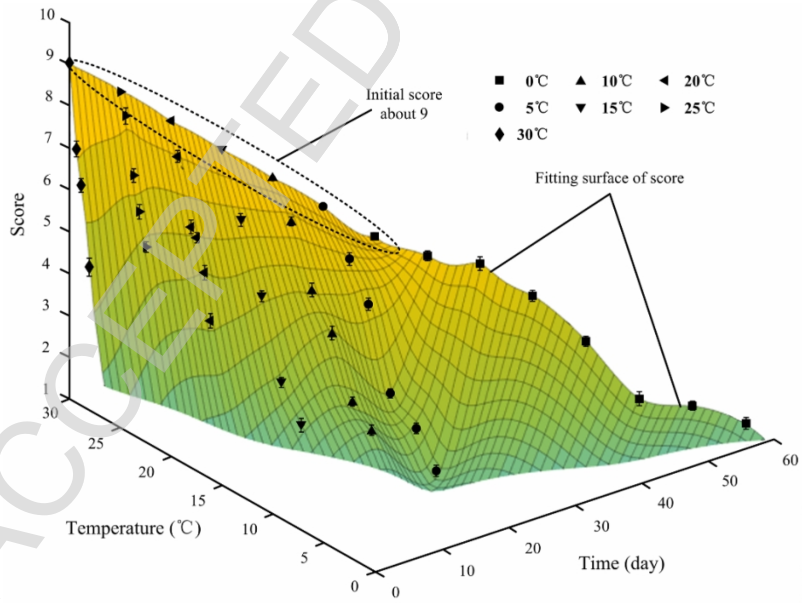

Fig. 8 The table grapes sensory evaluation at the critical temperatures

In all the cases, irrespective of the storage temperature, the table grapes quality was always in a state of declining, even at 0℃, the temperature at which was expected a preservation of the quality for a longer period of time. The table grapes firmness showed significant variation with the temperature, with an expected fall in firmness as the temperature increased. The table grapes moisture loss rate increased not only with the rising temperature, but also with the storage time. The moisture loss also plays a role in firmness evolution in the table grapes cold chain logistics. The sensory evaluation scores were also decreased as temperature increased. However, TSS and TA content have an unstable variation because the measurements may be affected by the environment and other subjective factors (Ye, Yue, Yuan, & Li, 2014).

3.3 Correlation analysis of quality parameters

According to the measurement results in Experiment II, the Pearson correlation coefficient between the sensory evaluation and the other initial quality parameters of table grapes, as shown in Figure 9, was calculated.

The Pearson correlation coefficients between the sensory evaluation and the firmness, the sensory evaluation and the moisture loss rate were all greater than 0.9, meaning that these two quality parameters are best correlated with the sensory evaluation of the table grapes. While the Pearson correlation coefficients between the sensory evaluation and the TSS, the sensory evaluation and the TA were all unstable. Therefore, these two quality parameters, firmness and moisture loss rate, could be considered as the critical quality parameters for the evaluation of the table grapes quality at the critical temperatures, and particularly in the table grapes cold chain logistics (Carreno et al., 2015).

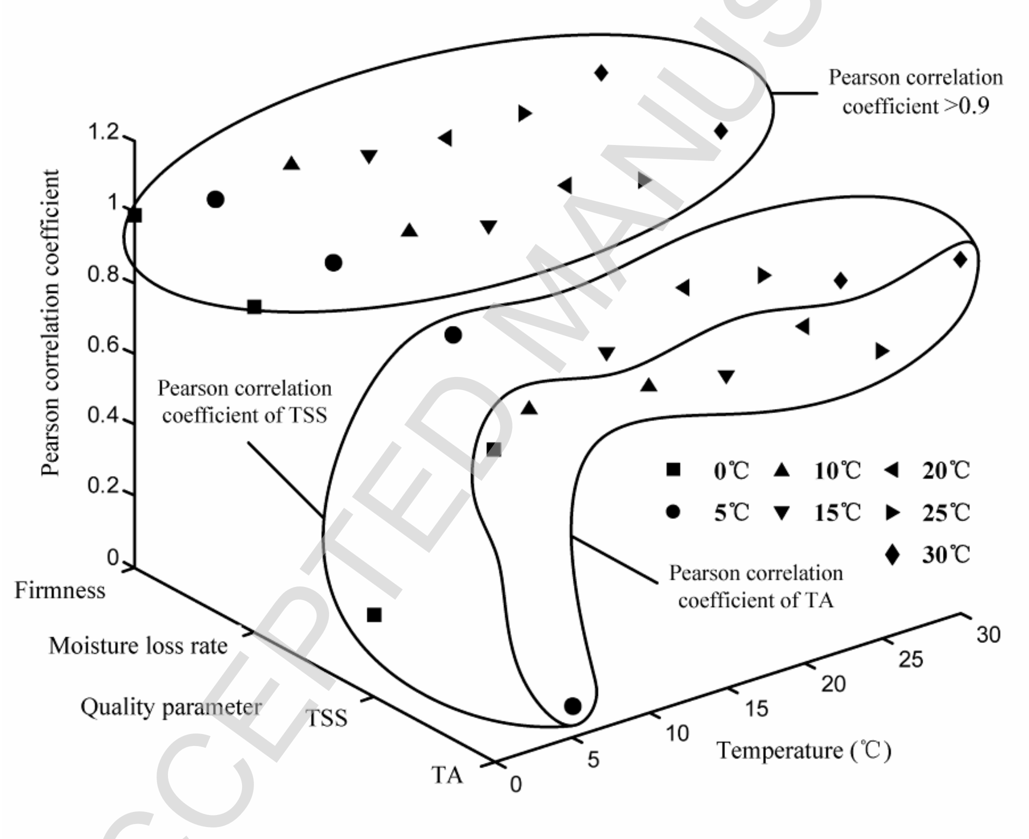

Fig. 9 The Pearson correlation coefficient between the sensory evaluation and the other initial quality parameters of table grapes

3.4 Critical quality parameters analysis

As determined in Experiment II, the critical quality parameters of table grapes were measured as in Experiment III at the temperature fluctuation conditions monitored in Experiment I. The firmness and moisture loss rate evolutions at the temperature fluctuation conditions were presented in Figure 10 and Figure 11 respectively.

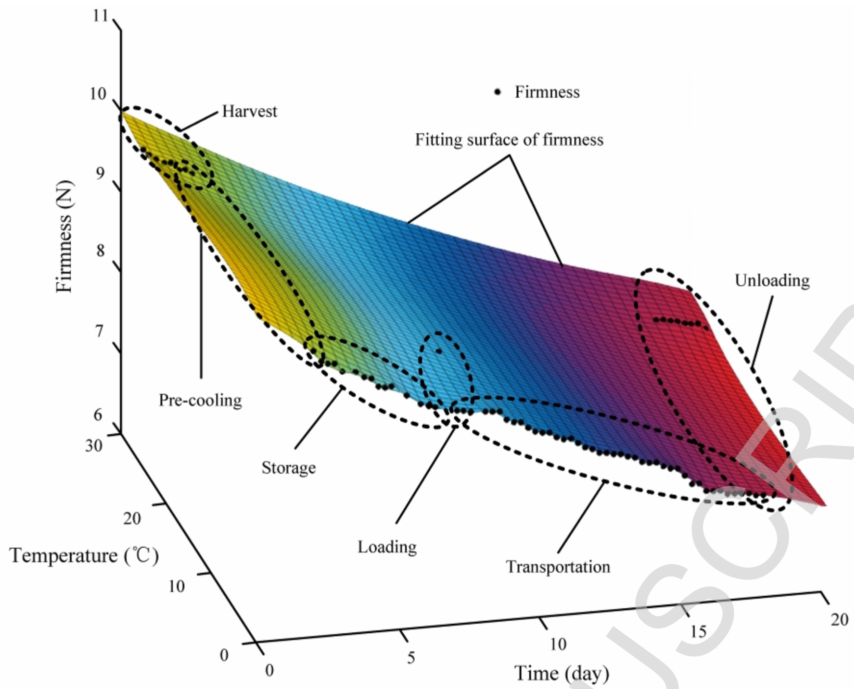

Fig. 10 The table grapes firmness evolution at the temperature fluctuation conditions

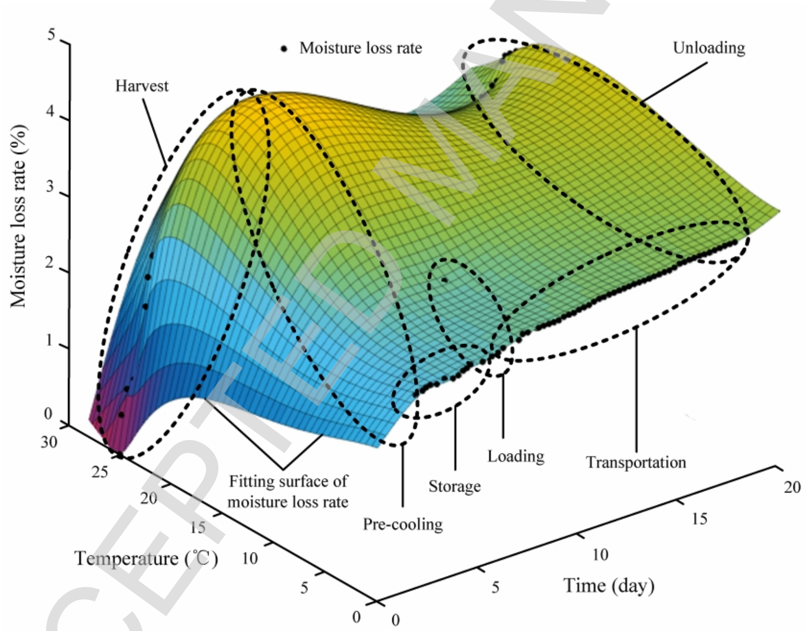

Fig. 11 The table grapes moisture loss rate evolution at the temperature fluctuation conditions

The table grapes firmness decreased over time in the table grapes cold chain logistics, in the same way as it was observed in the incubators with critical temperatures in Experiment II. The table grapes moisture loss rate also increased as the temperature rose, or vice versa, even though the constant relative humidity condition was set as in Experiment III.

The measurement results indicate that the critical quality parameters evolutions at the temperature fluctuation conditions monitored in Experiment I have the same variation as they were observed in the incubators with critical temperatures in Experiment II. The critical quality parameters of table grapes, firmness and moisture loss rate, could be reliable indicators of table grapes quality (Gwanpua et al., 2015). The decline of firmness and the increase of moisture loss rate were all slower in the cold chain logistics than those in the case of above 0℃

critical temperatures at the same period of time. This is because the table grapes were managed to keep at about 0 ℃ most of the time in the cold chain logistics.

3.5 Quality evaluation analysis of table grapes

As the correlation analysis in Experiment II and the measurement results in Experiment III, the table grapes quality in the cold chain logistics could be evaluated by the Arrhenius kinetic equation based on the firmness and moisture loss rate (Fortea, López-Miranda, Serrano-Martínez, Carreño, & Núñez-Delicado, 2009).

The quality evaluation models of table grapes based on the firmness and moisture loss rate, which calculated by the liner regression according to the measurement results in Experiment II and Experiment III, are described as equation (2) and equation (3).

$$t_{firmness} = \frac{C_{t_{firmness}} - C_{0_{firmness}}}{(1.28E+12)\times \exp\left(-\dfrac{6.848E+4}{8.314\times T}\right)} \tag{2}$$

$$t_{moisture} = \frac{\ln C_{t_{moisture}} - \ln C_{0_{moisture}}}{(3.05E+10)\times \exp\left(-\dfrac{6.354E+4}{8.314\times T}\right)} \tag{3}$$

where T is the storage temperature which is expressed in K, $t_{firmness}$ and $t_{moisture}$ are the predicted shelf life of the table grapes based on the firmness and moisture loss rate evaluation model at T, $C_{0_{firmness}}$ and $C_{0_{moisture}}$ are the initial value of the table grapes firmness and moisture loss rate, $C_{t_{firmness}}$ and $C_{t_{moisture}}$ are the final value of the table grapes firmness and moisture loss rate at T.

The table grapes prediction and observation shelf life at 0℃ in Experiment II is described in Table 1. The evaluation model based on the firmness is better to predict the table grapes shelf life than that based on the moisture loss rate. The relative error between the prediction and observation shelf life of table grapes is about 3.45% and 7.14% respectively.

Table 1. The table grapes prediction and observation shelf life at 0℃

Quality parameters	Prediction value (day)	Measurement value (day)	Relative error (%)
Firmness	56	58	3.45%
Moisture loss rate	52	56	7.14%

4. Conclusions

This paper contributes to improve the traceability and transparency of the table grapes quality as well as the sustainability performance of the table grapes cold chain logistics by determining the critical quality parameter(s) of table grapes in the cold chain logistics, and ensure the quality and safety of table grapes. The critical quality parameter(s) of table grapes in cold chain logistics was determined through the real time monitoring of the temperature fluctuation implemented with the WSN, and the correlation analysis among the various quality parameters of table grapes. Three experiments were conducted to assess the table grapes quality in the cold chain logistics.

Experiment I indicated that the temperature monitored by the WSN in the table grapes cold chain logistics have a large fluctuation, whose maximum range is about 30℃ when table grapes were harvested and sold, and minimum range is about 0℃ when stored and transported, and the critical temperatures could be determined as 0 ℃, 5℃,10℃, 15℃, 20℃, 25℃ and 30℃, to reflect the table grapes quality as comprehensive as possible.

Experiment II described that the initial quality parameters of the table grapes were all affected by the temperature, and the firmness and moisture loss rate could be the critical quality parameters by the Pearson correlation coefficient analysis between the sensory evaluation and the other initial quality parameters.

Experiment III illustrated that the critical quality parameters, firmness and moisture loss rate, could be reliable indicators of table grapes quality by the Arrhenius kinetic equation. The firmness and moisture loss rate evolutions at the temperature fluctuation conditions monitored in Experiment I have the same variation as they were observed in the incubators with critical temperatures in Experiment II, and the evaluation model based on the firmness is better to predict the shelf life than that based on the moisture loss rate.

The table grapes quality could be easily and directly traced and controlled in real time via the measurement of the critical quality parameters in actual cold chain logistics. The transparency as well as the sustainability performance of the table grapes cold chain logistics could be improved in further, and the best quality table grapes could be also provided for the consumers.

The results of this study provide some theoretical basis for the assessment of the table grapes quality in cold chain logistics, which can be used by producers and distributors in the further planning of their cold chain logistics, in order to maintain a good economic value of their products.

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References

Adler, J., & Parmryd, I. (2010). Quantifying Colocalization by Correlation: The Pearson Correlation Coefficient is Superior to the Mander's Overlap Coefficient. *Cytometry Part A, 77A*(8), 733-742.

Ahlgren, P., Jarneving, B., & Rousseau, R. (2003). Requirements for a cocitation similarity measure, with special reference to Pearson's correlation coefficient. *Journal of the American Society for Information Science and Technology, 54*(6), 550-560.

Akaberi, M., & Hosseinzadeh, H. (2016). Grapes (Vitis vinifera) as a Potential Candidate for the Therapy of the Metabolic Syndrome. *Phytotherapy Research, 30*(4), 540-556.

Aung, M. M., & Chang, Y. S. (2014a). Traceability in a food supply chain: Safety and quality perspectives. *Food Control, 39*, 172-184.

Aung, M. M., & Chang, Y. S. (2014b). Temperature management for the quality assurance of a perishable food supply chain. *Food Control, 40*, 198-207.

Balic, I., Ejsmentewicz, T., Sanhueza, D., Silva, C., Peredo, T., Olmedo, P., Barros, M., Verdonk, J. C., Paredes, R., Meneses, C., Prieto, H., Orellana, A., Defilippi, B. G., & Campos-Vargas, R. (2014). Biochemical and physiological study of the firmness of table grape berries. *Postharvest Biology and Technology, 93*, 15-23.

Brummell, D. A. (2006). Cell wall disassembly in ripening fruit. *Functional Plant Biology, 33*(2), 103-119.

Cai, H., Yuan, X., Pan, J., Li, H., Wu, Z., & Wang, Y. (2014). Biochemical and Proteomic Analysis of Grape Berries (Vitis labruscana) during Cold Storage upon Postharvest Salicylic Acid Treatment. *Journal of Agricultural and Food Chemistry, 62*(41), 10118-10125.

Carreno, I., Antonio Cabezas, J., Martinez-Mora, C., Arroyo-Garcia, R., Luis Cenis, J., Martinez-Zapater, J. M., Carreno, J., & Ruiz-Garcia, L. (2015). Quantitative genetic analysis of berry firmness in table grape (Vitis vinifera L.). *Tree Genetics & Genomes, 11*(1).

Champa, W. H., Gill, M., Mahajan, B., & Arora, N. (2015). Preharvest salicylic acid treatments to improve quality and postharvest life of table grapes (Vitis vinifera L.) cv. Flame Seedless. *Journal of Food Science and Technology, 52*(6), 3607-3616.

Correa, E. C., Jimenez-Ariza, T., Diaz-Barcos, V., Barreiro, P., Diezma, B., Oteros, R., Echeverri, C., Arranz, F. J., & Ruiz-Altisent, M. (2014). Advanced Characterisation of a Coffee Fermenting Tank by Multi-distributed Wireless Sensors: Spatial Interpolation and Phase Space Graphs. *Food and Bioprocess Technology, 7*(11), 3166-3174.

Coulomb, D. (2008). Refrigeration and cold chain serving the global food industry and creating a better future: two key IIR challenges for improved health and environment. *Trends in Food Science & Technology, 19*(8), 413-417.

Fortea, M., López-Miranda, S., Serrano-Martínez, A., Carreño, J., & Núñez-Delicado, E. (2009). Kinetic characterisation and thermal inactivation study of polyphenol oxidase and peroxidase from table grape (Crimson Seedless). *Food Chemistry, 113*(4), 1008-1014.

Freitas, P. M., López-Gálvez, F., Tudela, J. A., Gil, M. I., & Allende, A. (2015). Postharvest treatment of table grapes with ultraviolet-C and chitosan coating preserves quality and increases stilbene content. *Postharvest Biology and Technology, 105*, 51-57.

Fu, Z., Yao, M., Ma, C., Qi, L., & Zhang, X. (2013). Applicability of a chemical time temperature indicator as a quality indicator for table grape. *Journal of China Agricultural University, 18*(6), 186-191.

Giacosa, S., Marengo, F., Guidoni, S., Rolle, L., & Hunter, J. J. (2015). Anthocyanin yield and skin softening during maceration, as affected by vineyard row orientation and grape ripeness of Vitis vinifera L. cv. Shiraz. *Food Chemistry, 174*, 8-15.

Giacosa, S., Zeppa, G., Baiano, A., Torchio, F., Rio Segade, S., Gerbi, V., & Rolle, L. (2015). Assessment of sensory firmness and crunchiness of tablegrapes by acoustic and mechanical properties. *Australian Journal of Grape and Wine Research, 21*(2), 213-225.

Gwanpua, S. G., Verboven, P., Leducq, D., Brown, T., Verlinden, B. E., Bekele, E., Aregawi, W., Evans, J., Foster, A., Duret, S., Hoang, H. M., van der Sluis, S., Wissink, E., Hendriksen, L. J. A. M., Taoukis, P., Gogou, E., Stahl, V., El Jabri, M., Le Page, J. F., Claussen, I., Indergardi, E., Nicolai, B. M., Alvarez, G., & Geeraerd, A. H. (2015). The FRISBEE tool, a software for optimising the trade-off between food quality, energy use, and global warming impact of cold chains. *Journal of Food Engineering, 148*, 2-12.

Jang, M. S., Cai, E. N., Udeani, G. O., Slowing, K. V., Thomas, C. F., Beecher, C. W. W., Fong, H. H. S., Farnsworth, N. R., Kinghorn, A. D., Mehta, R. G., Moon, R. C., & Pezzuto, J. M. (1997). Cancer chemopreventive activity of resveratrol, a natural product derived from grapes. *Science, 275*(5297), 218-220.

Jiao, W., Fu, Z., Mu, W., McLaughlin, N., & Xu, M. (2012). Influence of supply chain model on quality and safety control of table grape and performance of small-scale vinegrowers in China. *British Food Journal, 114*(6-7), 978-996.

Kantsadi, A. L., Apostolou, A., Theofanous, S., Stravodimos, G. A., Kyriakis, E., Gorgogietas, V. A., Chatzileontiadou, D. S. M., Pegiou, K., Skamnaki, V. T., Stagos, D., Kouretas, D., Psarra, A. M. G., Haroutounian, S. A., & Leonidas, D. D. (2014). Biochemical and biological assessment of the inhibitory potency of extracts from vinification byproducts of Vitis vinifera extracts against glycogen phosphorylase. *Food and Chemical Toxicology, 67*, 35-43.

Kim, I.-H., Oh, Y. A., Lee, H., Bin Song, K., & Min, S. C. (2014). Grape berry coatings of lemongrass oil-incorporating nanoemulsion. *Lwt-Food Science and Technology, 58*(1), 1-10.

Kim, W. R., Aung, M. M., Chang, Y. S., & Makatsoris, C. (2015). Freshness Gauge based cold storage management: A method for adjusting temperature and humidity levels for food quality. *Food Control, 47*, 510-519.

Lim, T. P., Chye, F. Y., Sulaiman, M. R., Suki, N. M., & Lee, J. S. (2016). A structural modeling on food safety knowledge, attitude, and behaviour among Bum Bum Island community of Semporna, Sabah. *Food Control, 60*, 241-246.

Ma, C., Fu, Z., Xu, M., Trebar, M., & Zhang, X. (2016). Evaluation on home storage performance of table grape based on sensory quality and consumers' satisfaction. *Journal of Food Science and Technology*, 1-8.

Mirdehghan, S., & Rahimi, S. (2016). Pre-harvest application of polyamines enhances antioxidants and table grape (Vitis vinifera L.) quality during postharvest period. *Food Chemistry, 196*, 1040-1047.

Ngcobo, M. E., Delele, M. A., Chen, L., & Opara, U. L. (2013). Investigating the potential of a humidification system to control moisture loss and quality of 'Crimson Seedless' table grapes during cold storage. *Postharvest Biology and Technology, 86*, 201-211.

Ngcobo, M. E. K., Pathare, P. B., Delele, M. A., Chen, L., & Opara, U. L. (2013). Moisture diffusivity of table grape stems during low temperature storage conditions. *Biosystems Engineering, 115*(3), 346-353.

Parreno-Marchante, A., Alvarez-Melcon, A., Trebar, M., & Filippin, P. (2014). Advanced traceability system in aquaculture supply chain. *Journal of Food Engineering, 122*, 99-109.

Puth, M. T., Neuhauser, M., & Ruxton, G. D. (2014). Effective use of Pearson's product-moment correlation coefficient Comment. *Animal Behaviour, 93*, 183-189.

Porep, J. U., Walter, R., Kortekamp, A., & Carle, R. (2014). Ergosterol as an objective indicator for grape rot and fungal biomass in grapes. *Food Control, 37*, 77-84.

Qi, L., Xu, M., Fu, Z., Mira, T., & Zhang, X. (2014). (CSLDS)-S-2: A WSN-based perishable food shelf-life prediction and LSFO strategy decision support system in cold chain logistics. *Food Control, 38*, 19-29.

Raposo, A., Carrascosa, C., Perez, E., Saavedra, P., Sanjuan, E., & Millan, R. (2015). Vending machines: Food safety and quality assessment focused on food handlers and the variables involved in the industry. *Food Control, 56*, 177-185.

Sato, A., Yamane, H., Hirakawa, N., Otobe, K., & Yamada, M. (1997). Varietal differences in the texture of grape berries measured by penetration tests. *Vitis, 36*(1), 7-10.

Solyom, K., Kraus, S., Mato, R. B., Gaukel, V., Schuchmann, H. P., & Jose Cocero, M. (2013). Dielectric properties of grape marc: Effect of temperature, moisture content and sample preparation method. *Journal of Food Engineering, 119*(1), 33-39.

Sweetman, C., Sadras, V. O., Hancock, R. D., Soole, K. L., & Ford, C. M. (2014). Metabolic effects of elevated temperature on organic acid degradation in ripening Vitis vinifera fruit. *Journal of Experimental Botany, 65*(20), 5975-5988.

Tzamalis, P., Panagiotakos, D., & Drosinos, E. (2016). A 'best practice score'for the assessment of food quality and safety management systems in fresh-cut produce sector. *Food Control, 63*, 179-186.

Wiedermann, W., & Hagmann, M. (2016). Asymmetric properties of the Pearson correlation coefficient: Correlation as the negative association between linear regression residuals. *Communications in Statistics-Theory and Methods, 45*(21), 6263-6283.

Xiao, X., Qi, L., Fu, Z., & Zhang, X. (2013). Monitoring method for cold chain logistics of table grape based on compressive sensing. *Transactions of the Chinese Society of Agricultural Engineering, 29*(22), 259-266.

Xiao, X., Wang, X., Zhang, X., Chen, E., & Li, J. (2015). Effect of the Quality Property of Table Grapes in Cold Chain Logistics-Integrated WSN and AOW. *Applied Sciences, 5*(4), 747-760.

Xu, G. B., Shen, W. M., & Wang, X. B. (2014). Applications of Wireless Sensor Networks in Marine Environment Monitoring: A Survey. *Sensors, 14*(9), 16932-16954.

Ye, M., Yue, T., Yuan, Y., & Li, Z. (2014). Application of FT-NIR Spectroscopy to Apple Wine for Rapid Simultaneous Determination of Soluble Solids Content, pH, Total Acidity, and Total Ester Content. *Food and Bioprocess Technology, 7*(10), 3055-3062.