

Heat Transfer and External Quality Attributes of ‘Regal Seedless’ Table Grapes inside Multi Layered Packaging during Postharvest Cooling and Storage

M.E.K. Ngcobo^{1,2*}, M.A. Delele¹ and Umezuruike Linus Opara¹

¹Postharvest Technology Research Laboratory, Department of Horticultural Science, Faculty of AgriSciences, University of Stellenbosch, Private Bag X1, Matieland 7602, South Africa

²Perishable Products Export Control Board, 42 Silwerboom Avenue, Platteklouf, Parow, 7500, South Africa

G.D. Thiart and C.J. Meyer

Department of Mechanical and Mechatronics Engineering, Faculty of Engineering, University of Stellenbosch, Private Bag X1, Matieland 7602, South Africa

*Corresponding author, e-mail address: Tel: +27 21 930 1134; Fax: +27 21 808 3743; E-mail: ngcobom@ppecb.com (M.E.K. Ngcobo)

Keywords. ‘Regal seedless’ table grapes; Heat transfer; Packaging liners; Postharvest quality

Abstract

Postharvest packaging of table grapes is characterized by multi-layer packaging comprising of the carton box, the inner liner film, the individual bunch carry-bag and the SO₂ sheet. This multi-layered packaging is required to allow sufficient airflow to efficiently cool packed grapes in order to preserve quality. Total pressure drop and cooling rates of different table grape packaging systems were measured and the percentage contributions of each package component and the fruit bulk were determined. Also, the effects of different carton liners on the cooling rate and external quality attributes of table grapes were investigated. Fruit quality attributes measured included stem dehydration and browning, SO₂ injury and decay. On average the liner films contributed significantly higher to total pressure drop (61.04±15.91 %) than other components of the package combinations. Compared with the cooling of bulk grape bunches, the presence of the bunch carry bag increased the half and seven-eighth cooling time by 61.1 % and 97.3 %, respectively. The addition of plastic liners over the bunch carry bag increased the half and seven-eighth cooling time by 168.9 % and 185.2 %, respectively. Non-perforated liners maintained relative humidity (RH) close to 100 % during cold storage and during a 7-day shelf-life period which resulted in delaying the loss of stem quality but significantly ($P \leq 0.05$) while increasing the incidence of SO₂ injury and berry drop during storage compared with perforated liners.

INTRODUCTION

In most fresh food refrigeration systems, heat is transferred primarily by forced convection, where cold air is forced through food packages; therefore, the temperature and its homogeneity is largely governed by the patterns of the airflow (Smale *et al.*, 2006; Zou *et al.*, 2006). Table grapes are non-climacteric fruit and therefore should be harvested when reaching optimum maturity (Ginsburg *et al.*, 1978; Hardenburg *et al.*, 1986). However, fruit

quality tends to deteriorate rapidly during postharvest handling and storage, thus reducing shelf-life during marketing. Deterioration of table grape quality is mainly characterised by stem (rachis) dehydration and browning, fruit weight loss and colour change, accelerated berry softening, berry shatter and high incidence of berry decay due mainly to *Botrytis cineria*. Table grapes are packed in multi-layered packaging which includes the carton boxes with multiple inner-packaging materials including carton liner films, SO₂ pads, moisture absorption sheets and bunch carry bags (Ngcobo *et al.*, 2011). Resistance to airflow may even be higher during table grape cooling due to the fact that berry bunches are packed inside multi-layered packages. It is therefore important to understand the effects of packaging materials and produce on airflow in order to fully understand cooling patterns and moisture transfer properties for the design of efficient cooling systems. The aim of this experiment was to investigate the effects of multi-layered packaging on airflow and cooling patterns and on external quality attributes of table grapes during cooling and storage.

MATERIALS AND METHODS

Fruit supply

‘Regal Seedless’ grapes were obtained from the Hexriver area of the Western Cape, South Africa. The size of the grapes used was extra-large (diameter of 21.15±0.13mm). The airflow resistance experiments were carried out in the wind tunnel at the Mechanical and Mechatronics laboratory at Stellenbosch University, South Africa.

Packaging materials

The majority of export table grapes are packed inside 4.5 kg cartons with dimensions of 400 mm x 300 mm x 118 mm which are lined inside with polyethylene liner films. The physical characteristics of the liner films used included non-perforated; 54 x 2 mm² perforated; 36 x 4 mm² perforated and 120 x 2 mm² perforated liner films. Each carton of fruit was packed as follows: the carton was lined with a liner bag and corrugated ruffle sheets placed at the bottom of the liner bag to protect produce against bruising; grape bunches were then packed inside carry bags and each carry bag was placed carefully inside the liner; when the box was packed to full capacity, a moisture absorption sheet was placed on top of the packed bunches and finally an SO₂ pad (Proteku Grape Guard, INSUMOS FRUTICOLAS S.A., Chile) was placed on top of the absorption sheet to protect the grapes from a direct contact with the SO₂ pad (Zoffoli *et al.*, 2008). Once packing was complete, the liner was folded and sealed with a plastic tape to enclose the grapes together with inner packages.

Pressure loss

The wind tunnel setup and pressure drop measurements for the different package combinations were carried out according to Ngcobo *et al.* (2012a).

Cooling rate

Cooling experiments were conducted for the complete grape packages in an experimental cold storage room. The study was carried out using packaging and liner combinations in addition to grapes packed in bulk. Fruit temperatures were measured with a Logtag temperature probe (LogTag Recorder Limited, Northcote, Auckland, New Zealand). Cooling was achieved by placing two carton boxes with the same multi-scale packaging configuration adjacent to each other on a pallet. Every experiment was repeated three times.

The velocity of the approaching cold air was 3 m.s⁻¹. The 1/2 and 7/8 cooling times were calculated according to Ngcobo *et al.* (2012b). The measured temperature was presented in the form of dimensionless temperature using the initial pulp temperature and the cooling air temperature as per Eq.1:

$$\theta = \frac{T - T_{\infty}}{T_i - T_{\infty}} \quad ? \quad (1)$$

Where T , is the fruit pulp temperature (°C); T_i , is the initial pulp temperature (°C); and T_{∞} , is the temperature of the cooling air (°C).

External fruit quality assessment measurement

Fruit quality measurements were carried out on the day of harvest (day 0) and every consecutive week (after 7 days) for six weeks in cold storage. Final fruit quality was evaluated after 1-week shelf life at 24.3 °C. Quality attributes measured included stem dehydration and browning, bunch weight loss, berry drop, firmness, SO₂ injury colour and decay incidence.

Stem dehydration and stem browning: Stem dehydration was assessed using the following scoring system: fresh stems =1; some drying of thinner stems=2; all thinner stems dry=3; all thinner and some thicker stems dry=4; and all stems dry=5. Stem browning development was measured using the following scoring system: 1= fresh and green; 2 = some light browning; 3 = significant browning; 4 = severe browning.

Weight loss: The weight of individual bunches was measured with a weighing scale (EEW-5000, 5500g x 0.5g, UWE, SOUTH AFRICA). Bunch weight loss was expressed as percentage loss of the initial weight. Berry drop (%) was expressed as ratio of weight of loose berries over the bunch weight. The ratio was determined as the total weight of berries that were detached from the bunch stems (loose berries) and fallen inside each carry-bag and divided by the overall bunch weight inside that particular carry-bag.

SO₂ injury and decay incidence: SO₂ injury was rated according to the following scoring system: (1) none (0%); (2) slight damage (<5%); (3) moderate damage (5-10%); (4) severe damage (> 10 %). Decay was scored as follows: (1) no decay; (2) slight (< 2 infected berries per carton); (3) severe (2 – 5 infected berries); (4) extreme (>5 infected berries per carton)

RESULTS AND DISCUSSION

Airflow resistance multi-packages

Liner films contributed 61.04±15.09 % to the total airflow resistance of the complete multi-package combination (Figure.1) The carton box and the bunch carry bag contributed 26.81±9.90% and 7.22±3.51%, respectively. The grapes contribution was 4.93±2.95% of the total airflow resistance. This may be attributed to the fact that carry bags are well- ventilated and open at the top and hence a low resistance to airflow. The measured grape bunches porosity was 56.45±0.04% and the low resistance to airflow by grapes was due to this high porosity of the grape bunches.

Cooling rate of multiple packages

The half-cooling and seven-eighth cooling rates were significantly higher ($P < 0.05$) for the non-perforated liner films compared with the perforated liners (Table 1). The difference between the cooling rates of perforated liner films was not significant (Figure 2). The cooling of grapes in bulk was quicker in the absence of any of the inner packages. The addition of bunch carry-bags to bulk grapes cooling increased the half and seven-eighth cooling time by 61.1 % and 97.3 %, respectively. The addition of plastic liners over the bunch carry bag increased the half and seven-eighth cooling time up to 168.9 % and 185.2 %, respectively.

Stem condition

Non-perforated liner films retained relative humidity at 100 % while the relative humidity in perforated liners was below 95 % (Table 2). The effect of the difference in RH in the different liner films was evident in the stem condition of the bunches, where the non-perforated liners resulted in significantly less stem dehydration and browning than perforated liners.

SO₂ injury and decay incidence

Incidences of SO₂ injury were observed within the first seven days of cold storage on table grapes packed in non-perforated liners, while perforated liners showed no injury. However, after 42 days of cold storage the grapes packed in perforated liners started to show symptoms of SO₂ injury as well (Figure 3). The SO₂ injury incidence remained significantly ($P = 0.00$) higher on grapes packed in non-perforated liners than those packed in perforated liners. No incident of SO₂ injury was observed on grapes packed in 36 x 4mm perforated liner. These results confirm observations by Zoffoli et al. (2008) who suggest that hairline development, a symptom of SO₂ injury, could be partially explained by the acidic conditions developed on berry surfaces after the SO₂ contact with water vapour. The combination of free water (100 % RH) and SO₂ in the non-perforated liner may have resulted in a formation of acidic conditions that may have increased SO₂ injury in this study.

No incidence of decay was observed prior to the shelf life study, indicating that table grapes require packages that allow good cooling and need good cold chain management to ensure retarding the development of decay. However, after the shelf life a high incidence of decay occurred (Figure 3) and decay nests were observed in all fruit packages. This development of decay during shelf life study may be attributed to the germination of the *Botrytis cineria* spores that takes place when storage conditions of high humidity and high temperature prevail (Ginsburg et al., 1978).

CONCLUSIONS

Liner films contributed far more to airflow resistance than other package components of the grapes multi-packaging. Addition of each package component resulted in a reduction in cooling rates. Cooling rates were more rapid for fruit in bulk, the grapes packed in multi-packages. Although non-perforated liner films retained 100 % relative humidity, they tended to result in higher SO₂ injury incidence probably due to the formation of acidic condition due to the SO₂ sheet in the presence of free water. Further work is required to focus on the improvement of ventilation of table grapes packaging in order to improve airflow and cooling efficiency.

ACKNOWLEDGEMENT

This research is based upon research supported by the South African Research Chairs Initiative of the Department of Science and Technology and National Research Foundation. The financial support of the South African Postharvest Innovation Programme (PHI-2) through the award of a research project on “Packaging of the Future” is gratefully acknowledged.

LITERATURE CITED

- Hardenburg R.E., Watada A.E., Wang C.Y.. The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks. USDA Handbook, Government Printing Office: Washington, DC, 1986.
- Ginsburg L, Combrink JC, Truter AB. 1978. Long and short term storage of table grapes. *Int. J. Refrig.*, 1, 137 – 142
- Ngcobo M.E.K., Delele M.A., Opara U.L., Zietsman C.J., Meyer C.J. 2012a. Resistance to airflow and cooling patterns through multi-scale packaging of table grapes. *Int. J. Refrig.*, 35 (2), 445-452.
- Ngcobo M.E.K., Opara U.L., Thiart G.D. 2012b. Effects of packaging liners on cooling rate and quality attributes of table grape (cv. Regal seedless). *Packaging Technol.Sci.*, 25 (2), 73-84.
- Smale N.J., Moureh J., Cortella G. 2006. A review of numerical models of airflow in refrigerated food applications. *Int. J. Refrig.* 29: 911 – 930.
- Zou Q., Opara L.U., McKibbin R. 2006. A CFD modelling system for airflow and heat transfer in ventilated packaging for fresh foods: I. Initial analysis and development of mathematical models. *J. Food Eng.*, 77 1037-1047.
- Zoffoli J.P., Latorre B.A., Naranjo P. 2008. Hairline, a postharvest cracking disorder in table grapes induced by sulfur dioxide. *Postharv. Biol. and Technol.*, 47, 90 – 97.

Table 1: Cooling rates comparisons of table grapes inside multi-packages

Packaging liner film	Cooling times (min)	
	1/2 cool	7/8 cool
Non -perforation	470.5	1410.5
169.6 mm ² perforation	422.5	1239
<i>Significance level</i>	<i>P = 0.0074</i>	<i>P = 0.0026</i>
Non-perforation	470.5	1410.5
376.9 mm ² perforation	415	1245
<i>Significance level</i>	<i>P = 0.0031</i>	<i>P = 0.0067</i>
Non-perforation	470.5	1410.5
452.4 mm ² perforation	428.75	1284.5

*Significance level**P = 0.0188**P = 0.0132*

Table 2: Effect of different packaging liners on RH and stem quality of 'Regal Seedless' table grapes

every consecutive week (after 7 days) for six weeks in cold storage. Final fruit quality was evaluated after 1-week shelf life at 24.3 °C. Quality attributes measured included stem dehydration and browning, bunch weight loss, berry drop, firmness, SO₂ injury colour and decay incidence.

Packaging	% Relative humidity	Stem dehydration (1 – 5)*	Stem browning (1 – 4)**
After 14 days at -0.5°C			
Non perforations	100.0c	3.7a	2.2a
36x4mm perforation	92.3b	4.6b	2.9b
54x2mm perforation	91.9b	4.7b	2.9b
120x2mm perforation	92.2b	4.8b	3.2b
After 42 days at -0.5°C			
Non perforations	100.0e	4.5a	2.7a
36x4mm perforation	92.7c	5.0b	3.8c
54x2mm perforation	91.7a	5.0b	3.6bc
120x2mm perforation	93.0d	5.0b	3.7bc
Shelf life: 7 days 24.3 °C			
Non perforations	100.0b	4.8a	2.8a
36x4mm perforation	88.8a	5.0b	3.9c
54x2mm perforation	91.1a	5.0b	3.7bc
120 X 2mm perforation	89.9a	5.0b	3.8c

*Score: 1= fresh stems; 2= some drying of thinner stems; 3 = all thinner stems dry; 4 = all thinner and some thicker stems dry; and 5 = all stems dry. **Score: 1 = fresh and green stems; 2 = some light browning of stems; 3 = significant browning of stems; and 4 = severe browning of stems. Values within a column followed by a different letter within a block are significantly different ($P \leq 0.05$) according to Duncan tests.

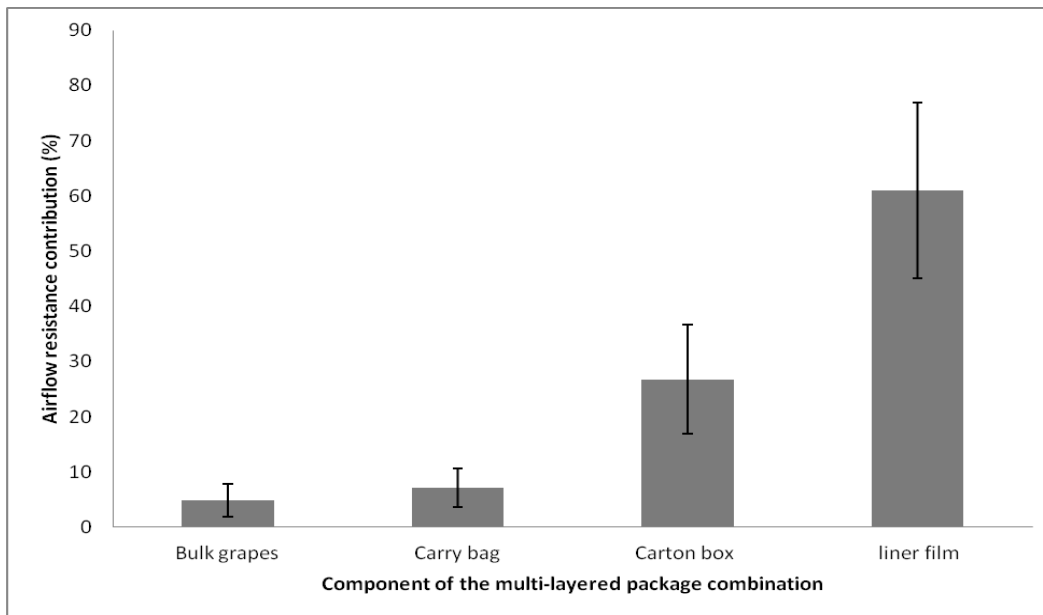


Figure 1: Percentage contribution (\pm SD) of the different packages and fruit to the total pressure drop of grape multi-scale packaging.

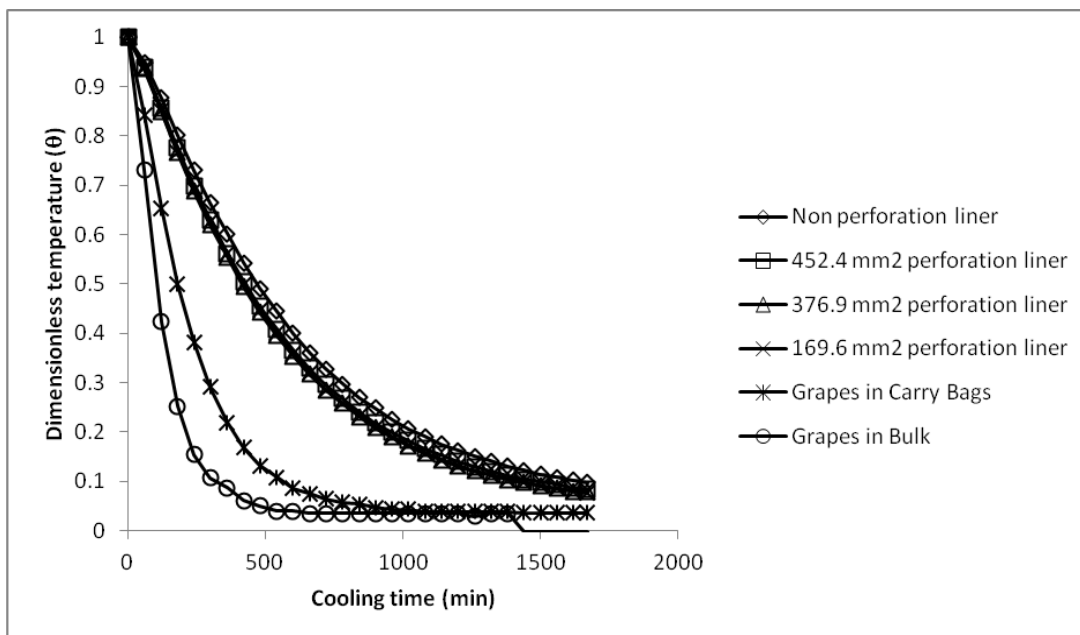


Figure 2: Cooling patterns of table grapes inside different multi-packages

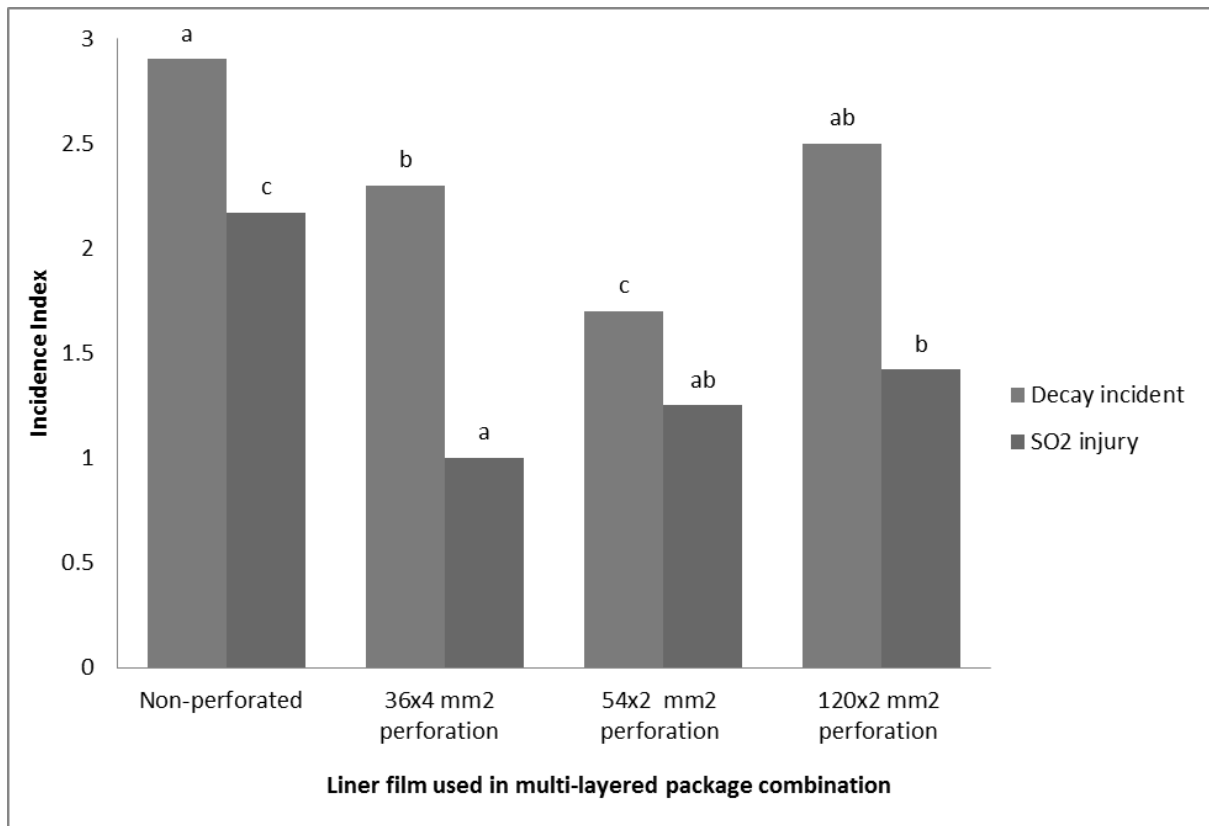


Figure 3: Incidence of SO₂ injury and decay after 42 days cold storage at -0.5°C and 7 days shelf life. The different letters show the significant differences (P < 0.05) according to Duncan tests.