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Performance of multi-packaging for table grapes based on airflow, cooling rates and fruit quality

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ABSTRACT

The performance of three table grapes multi-scale designs, namely the 4.5 kg box, 5 kg open-top punnet and 5 kg clamshell punnet, was studied. Results showed that vent-hole ratio of empty grape boxes had a significant influence on the resistance to airflow, where the 5 kg punnet box with a vent-hole ratio of 6.13 ± 0.04% had a lower pressure drop than the 4.5 kg boxes with a lower vent-hole ratio of 3.80 ± 1.74%. The addition of liner films and inner packages changed the pressure patterns, indicating that inner packaging had a great influence on airflow resistance and airflow patterns through multi-scale packages of grapes. Cooling rates of grapes in the 4.5 kg multi-packaging was significantly ($P < 0.05$) slower than that of grapes in 5 kg punnet multi-packaging, where the 4.5 kg box resulted in a seven-eighths cooling time of 30.30–46.14% and 12.69–25.00% more than that of open-top and clamshell punnet multi-packages, respectively. After 35 days in cold storage at −0.5 °C, grape bunches in the 5 kg punnet box combination (open-top and clamshell) had a weight loss of 2.01–3.12%, while the bunches in the 4.5 kg box combination had only 1.08% weight loss. The bunch stem dehydration rates were also higher in the 5 kg punnet multi-package. These results were attributed to differences in vapour pressure deficit (VPD) measured between the three multi-scale packages, where the VPD inside the 4.5 kg multi-packaging was 40.95 Pa, while the VPD inside the 5 kg open-top and clamshell punnet packaging were 92.97 Pa and 100.71 Pa, respectively.

1. Introduction

Precooling and refrigerated storage have been widely reported as effective techniques to preserve fruit quality and freshness after harvest, as these techniques tend to reduce the rate of biochemical reactions and microbiological growth (Baird and Gaffney, 1976; Brosnan and Sun, 2001; Dincer, 1991a, 1992; Dincer and Akaryildiz, 1993; Ginsburg et al., 1978; Thompson et al., 1998). Forced air cooling is one of the precooling techniques that is commonly used to remove the field heat from the freshly harvested fresh produce (de Castro et al., 2004; Hardenburg, 1986; Thompson et al., 1998). In forced air cooling systems heat is primarily transferred by convection, and therefore temperature and its homogeneity is largely governed by patterns of airflow (Smale et al., 2006; Zou et al., 2006).

Forced air cooling is usually commenced after the fruits have been packaged in carton boxes and stacked on pallets and therefore, it is important that the packaging used allows for sufficient airflow in order to achieve homogenous airflow and thus uniform cooling of packed fruits. Many studies have been reported on the resistance to airflow of fruit packages as a function of vent-hole ratio and shape (Chau et al., 1985; Vigneault and Goyette, 2002; Zou et al., 2006); bulk fruit stacking and porosity (Chau et al., 1985; Delele et al., 2008; Neale and Messer, 1976a,b; Neale and Messer, 1978; Verboven et al., 2004; van der Sman, 2002; Smale et al., 2004) and carton boxes stacking on a pallet (Delele et al., 2012). Fruit packaging and box stacking patterns are likely to contribute by far to airflow resistance, as the flow is strongly dependant on vent-area and alignment of vent-holes of stacked boxes (Ngcobo et al., 2012b; Delele et al., 2012). Poor ventilation of fruit packages may result in heterogeneous cooling of fruits within packages and between different packages in stacked pallets and this has been associated with poor fruit quality in previous studies (Smale et al., 2006).

Table grapes postharvest packaging is characterised by different types of multi-scale package combinations (Ngcobo et al., 2012a). These multi-scale packages are aimed at protecting the grapes against mechanical damage during postharvest handling and contamination from foreign matter. However, these multi-packages

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are also required to allow for sufficient and homogenous cooling in order to prolong pre-harvest grapes quality after harvest. Previous studies (Delele et al., 2012; Ngcobo et al., 2012a,b) have focused on investigating the effects of liner films; and 4.5 kg boxes stacking on the resistance to airflow; cooling rates and patterns respectively. The results obtained from these studies have shown that the plastic liner films component of the multi-scale packaging contributed the highest (ranging from 40.33 ± 1.15% for micro-perforated liner film to 83.34 ± 2.13% for non-perforated liner film) to airflow resistance (Delele et al., 2012; Ngcobo et al., 2012b). The multi-scale packages may well cause heterogeneous grape cooling which results in postharvest quality variation observed despite the great efforts put in ensuring efficient pre-cooling and good temperature management in the cool chain.

Poor quality in table grapes includes weight loss, stem (rachis) dehydration and browning, colour changes, accelerated berry softening, berry shatter and high incidence of berry decay due mainly to *Botrytis cineria* and incidence of SO_2 injury (Ginsburg et al., 1978; Nelson, 1978; Ngcobo et al., 2012a; Zoffoli et al., 2008). The symptoms of SO_2 injury in grapes include a bleached discolouration of the affected area of the berries, and sometimes the affected area may appear sunken. Hairline cracking of berry skins has also been associated with SO_2 injury (Ngcobo et al., 2012a; Zoffoli et al., 2008). It is possible that grape postharvest quality problems may be associated with the type of multi-scale packaging combination used and therefore an investigation focused on the performance of the different commercially available types of grape packaging combinations is warranted.

The aim of this study was to evaluate the performance of different table grape package systems based on airflow, cooling and quality characteristics. The effects of box design, bunch carrying bag and punnet (open and clamshell) were analysed.

2. Materials and methods

2.1. Fruit supply

'Regal Seedless' grapes were sourced and packed at a commercial farm in the Worcester Area of Western Cape in South Africa. The fruits were then transported to the Postharvest Technology Lab at Stellenbosch University, where they were prepared for forced air cooling and cool storage trials.

2.2. Fruit packaging

The grapes were packed in three types of commercially used grape multi-packages (Fig. 1a and b) namely (i) the 4.5 kg boxes containing inner packages (120 × 2 mm perforated liner film; riffle sheet; bunch carry-bags; moisture absorption sheet and SO_2 pads); (ii) 5 kg boxes containing inner packages (112 × 4 mm perforated liner film; clamshell punnets; moisture absorption sheet and SO_2 pads); and (iii) 5 kg boxes containing inner packages (112 × 4 mm perforated liner film; open-top punnets; moisture absorption sheet and SO_2 pads).

2.3. Airflow studies

The resistance to airflow studies (pressure loss) of individual grape packaging components were carried out in a wind tunnel as detailed by Ngcobo et al. (2012b), in a stepwise manner as follows: (i) pressure loss over empty boxes orientated either with its length (L) or breadth (B) perpendicular to inflow (Fig. 2a and b); (ii) pressure loss over boxes containing empty punnets; (iii) pressure loss over boxes containing punnets with grape bunches; and (iv) the pressure loss over complete grape multi-package combinations (boxes plus liner film plus punnets containing fruits). The air velocities ranged from 0.70–3.21 ms^{-1}; 0.10–0.60 ms^{-1} and 0.02–0.20 ms^{-1} for empty wind tunnel, empty packages and fully packed multi-packages respectively. During forced air cooling of stacked grapes boxes, the approach air velocity was measures with a velometer (ALNOR, AVM440, Velometer®, TSI Inc., Shoreview, USA) with a high accuracy over a wide velocity range (0–30 m/s). The pressure loss of the flow through the bulk grapes and packages was measured by a pressure transducer device (PMD70-AAA7-D22AAU, ENDRESS + HAUSER, Weil am Rhein, Germany), with an accuracy of 0.075%.

2.4. Cooling system

Forced air cooling of grapes boxes was done using a moveable forced air cooler (Fig. 3) inside a refrigerated room. The air temperature inside the cool room was −0.5 °C, and was circulated by means of three fans (Delele et al., 2012). The fruits boxes were stacked on a pallet base and tightly positioned in front of the force air cooler (Fig. 3). The 5 kg punnet boxes were stacked up to 9 layers, with each layer containing 5 boxes as per Fig. 4a. The 4.5 kg boxes were stacked up to 5 layers, with each layer containing 10 boxes laid out as per Fig. 4b. A total mass of 225 kg was cooled at a time. Following the stacking of fruit boxes, strong plastic was then used to seal the sides and top of the fruit stack with the cooler in order to form a tunnel and to ensure that there was no air leakage when the cooler suction fan was switched on. After sealing with plastic, the cooler fan was switched on and sucked the cold room air through the stack and thus ensuring pre-cooling.

To avoid the negative effect of cooling and reheating on the quality of grapes during forced air cooling experiments, the fruit quality experiments were conducted separately from the forced air cooling trials and under static conditions inside cold room. Six grapes boxes of each multi-package used for quality measurements were therefore cooled through natural convection and store in a cool room at −0.5 °C and at 95% humidity.

2.5. Temperature and humidity measurements

Berry temperature was measured with Logtag pulp temperature probes with an accuracy of ±0.05 °C (LogTag Recorder Limited, Northcote, Auckland, New Zealand) inserted into inside each carton. Air temperature was measured with a LogTag air temperature recorder (LogTag Trix-8 temperature Recorder) at the central position inside each carton. Air relative humidity (%RH) inside each carton was measured with a SENSITECH TempTale 4 monitor with an accuracy of ±5% (Temptale4 Humidity and Ambient Temperature 16000, SENSITECH, Beverly, MA, USA).

2.6. Quality measurements

Quality attributes measured included stem dehydration and browning, bunch weight loss, SO_2 injury colour and decay incidence. The measurements were recorded at 7 days intervals under cold storage and for 35 days. The measuring procedure was done according to Ngcobo et al. (2012a) and is detailed as follows.

2.6.1. Bunch weight loss

The weight of individual bunches was measured with a weighing scale (Mettler, Toledo, Switzerland, with an accuracy of 0.01 g). Bunch weight loss data was normalised with respect to the initial bunch weight.

2.6.2. Stem drying and browning

Stem dehydration was assessed using the following scoring system: without drying (fresh stems) = 1, some drying of thinner