Geometric Design Characterisation of Ventilated Multi-scale Packaging Used in the South African Pome Fruit Industry

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Abstract

Ventilated corrugated cartons are the primary types of packaging used in export shipment of fresh fruit, including apples and pears. The use of inappropriately ventilated packaging can result in cooling heterogeneity and incidence of physiological disorders during cold chain handling of fresh fruit, and in extreme cases, mechanical damage of packaging and fruit. A survey on the types of ventilated packaging in South Africa showed that eleven different corrugated fibreboard carton designs were used in export handling of pome fruit, with Mk4 and Mk6 cartons accounting for the majority of those used apple (48 %) and pear (57 %), respectively. Each package design type is often used in several dimensional formats to accommodate different fruit sizes and market requirements. Overall, the different carton designs can be classified into 'Display' and 'Telescopic' packages, with four stacking configurations commonly used to palletise the cartons. Total ventilated area (TVA) per carton varied between 1.92 and 8.81 %., with average of 3.80 and 4.44 % for display and telescopic designs, respectively. Improper vent positioning on some packages may result in non -alignment of ventilation in stacked pallets, which in turn may alter airflow patterns during forced-air cooling.

Introduction

Fruit are living entities that deteriorate in quality as they respire and transpire, leading ultimately to senescence (Salisbury & Ross, 1992; Brosnan & Sun, 2001). Temperature is the most important factor in moderating fruit deterioration as it regulates the rates of biological reaction occurring inside fruit (Nelson, 1978; Ravindra & Goswami, 2008). Precooling is, therefore, used to reduce the temperature and thereby extend storage life of harvested fruit. Forced air cooling (FAC) is acknowledged as the most common precooling technique in the fruit industry to remove excess heat (De Castro, Vigneault, & Cortez, 2004a; Zou, Opara, & McKibbin, 2006) and is often performed after fruit packaging (Talbot & Baird, 1990; Ladaniya & Singh, 2000). Heat transfer between fruit and the cooling medium (cold air) is largely facilitated by ventilation holes in the walls of the stacked cartons, which allows airflow penetration through a pallet stack. During FAC, ventilation holes in the packaging should facilitate a homogenous cooling pattern throughout a stack of cartons by directing uniform airflow through the stack. The uniformity of airflow inside the package containing fruit is significantly affected by the

size and distribution of ventilation holes on the carton wall (de Castro *et al*., 2004a). Cooling efficiency is, however, affected by vent position and size, while the effect of the vent shape, is significantly influenced by several factors, such as the width of opening, position and container contents (Kader, 2002; Vigneault & Goyette, 2002). Carton strength is also significantly affected by the presence, size and shape of ventilation holes (Singh *et al*., 2008; Han & Park, 2007). The addition of ventilation holes should therefore not compromise the mechanical strength of the carton (Vigneault & Goyette, 2002; De Castro, Vigneault, & Cortez, 2004b; Vigneault & de Castro, 2005).

In order for a ventilated carton to function at optimum, cartons should have sufficient mechanical strength to protect the fruit (Robertson, 2006; Vigneault, Goyette, & De Castro, 2006), while supplying sufficient ventilation to maintain the cold chain. The ventilation should include holes at both the top and bottom, depending on design type (Vigneault & Goyette, 2002; De Castro *et al*., 2004b). According to Kader, (2002), a total vent area (TVA) of 5-6 % for fibreboard cartons is a good compromise between strength and ventilation area. However, de Castro *et al*. (2005) showed that TVA between 8 and 16 % results in the best air cooling efficiency. In earlier studies, the authors showed that TVA < 25 % significantly restricted airflow in ventilated containers (Vigneault & Goyette, 2002) However, such large open areas on the package could compromise the structural integrity of the package, especially paperboard based packaging.

Ventilated cartons are the most commonly used type of packaging used in the fruit industry. To meet the wide range of export and domestic market demands, different design of packaging are used resulting in geometrical configurations and sizes (Opara & Zou, 2007; Pathare, Opara, Vigneault, Delele, & Al-Said, 2012). Despite the availability of numerous designs , it has been reported that many packaging types used in the fruit industry are not effective in promoting fast and uniform cooling (Ferrua & Singh, 2007). Several authors have recommended that new packaging systems should be thoroughly evaluated to optimise ventilation design and ultimately improve cooling (Vigneault *et al*., 2006; Vigneault, Thompson, & Wu, 2009; Thompson, Mejia, & Singh, 2010; Pathare *et al*., 2012). In addition to improving technical (thermal and mechanical) efficiency of packaging, rising energy costs (Sebitosi, 2008) and the need to reduce packaging and fruit carbon footprint (Thompson *et al*., 2010) have heightened the need to re-examine the role of ventilated package design used in the agricultural industry. A wide range of ventilated packaging designs are used in the global postharvest handling and distribution of fruit. However, little is known about the geometric and ventilation characteristics of existing packages used in the industry to assist in formulating future designs to meet the technical and socio-environmental requirements of packaging. The objective of this study was, therefore, to quantify the geometric design characteristics of ventilated packaging used in the South African pome fruit (apples and pears) industry.

Material and Methods

Survey Methodology

The survey was carried by collecting samples of all available apple and pear cartons from major pack houses in two major pome fruit growing areas (Grabouw and Ceres) in the Western Cape Province, South Africa, as well as from the fresh produce section of major supermarkets in the province. The survey was performed between January and July 2012 and the Western Cape Province was chosen at the study area because it accounts for over 92 % of apples and pear production in South Africa (PPECB, 2013a).

Each package was examined based on three broad geometric characteristics: a) carton dimensions (length and width); b) ventilation (size and number of holes); and c) presence of internal packaging (polyethylene bags (polyliner), trays, punnets or thrift bags).

Data Analysis

Data on the usage of different cartons for fruit export were collected from the Perishable Products Export Control Board (PPECB, 2013b). Each package design was linked to a local 'pack code' which in turn is linked to a 'Global Trade Item Number' of fruit exports. The descriptive capabilities of the 'pack code' was found to be limited while classifying the packages, given that the same code may be used for different variations of similar carton designs produced by different packaging production companies. In addition, the 'pack code' may also be dissimilar for the same carton design if one of them contained differing internal packaging. Up to five samples of each carton design were examined and measured to verify the dimensions reported. Due the lack of differences in geometric characteristics of each type of carton, standard deviations of the data are not applicable.

Results and Discussion

Packaging Export Statistics

The main types of packaging used to export apples (**Table 1**) and pears (**Table 2**) from South Africa to various markets between 2008 and 2012 were obtained from export statistics (PPECB, 2013b). The data is clearly indicative of a market-driven

Table 1 Cartons of apples exported between 2008 and 2012 by carton type and region (PPECB, 2013b)

	Africa	America	Atlantic Ocean Isle	Australia	C/Europe	F/East & Asia	Indian Ocean Island	M/East & Medite-rranean	Unknown	Russia	United Kingdom	Total (%)
Bushel	41,662	23,046	0	0	15,793	556,139	42,217	623	1,767		2,993	0.61
Econo-D	357,224	450	0	0	341,579	22,186	15,752	215,224	16,151	5,643	66,007	0.93
Econo-T	107,555	3,702	0	216	1,219,051	58,707	18,546	127,153	9,434	28,146	268,021	1.65
Micro-D	1,129	0	0	0	0	0	140	115	0	0	75	0.00
Jumble	200,322	0	0	0	4,896	0	0	0	0	0	820	0.19
Mini-mk9	3,363	0	0	0	3,641	0	0	185	0	0	52,739	0.05
Mini-T	8,019	0	0	0	40,617	8,638	0	52,664	0	46	2252	0.10
Mk4	15,429,298	283,275	3,077	1,972	19,063,127	11,055,384	610,483	4,226,980	496,208	315,350	2,163,004	48.20
Mk6	645,613	11,824	414	20	2,025,115	149,666	22,747	1,198,346	81,847	402,308	184,527	4.24
Mk7	7,605	430	0	0	285,406	10,271	0	12,428	20	920	284,747	0.54
Mk9	109317	72,781	0	2	6,567,388	193,666	996	74,904	206,778	24,159	16,800,338	21.61
Other	2,533,227	67,924	62	0	4,239,058	1,508,911	35,286	1,025,067	35,351	85,689	14,528,043	21.61
Plastic	0	0	0	0	20,306	9,378	0	0	10,365	0	241,765	0.25
Total (%)	17.47	0.42	0.00	0.00	30.39	12.19	0.67	6.23	0.77	0.77	31.08	

Table 2 Cartons of pears exported between 2008 and 2012 by carton type and region (PPECB, 2013b)

	Africa	America	Atlantic Ocean Isle	Australia	C/Europe	F/East & Asia	Indian Ocean Island	M/East & Medite-rranean	Unknown	Russia	United Kingdom	Total (%)
Bushel	56	0	0	0	11,486	4,050	0	0	0	0	480	0.02
Econo-D	30,479	0	0	0	80,753	3,284	8	217	770		13,065	0.17
Econo-T	15,293	0	0	0	402,153	6,217	2,019	1,806	12,204	1,504	34,118	0.62
Micro-D	14,947	0	0	0	6,530	0	20	34	0	0	36	0.03
Jumble	2,363	0	0	0	0	0	0	63	0	0	0	0.00
Mini-mk9	1	0	0	0	43,857	0	70	13,636	0	0	10,070	0.09
Mini-T	62	280	0	0	314,732	1,095	700	0	16,585	80	4,290	0.44
Mk4	39,823	1,616	74	0	372,419	35,083	1,980	4,651	75,010	3,291	14,142	0.71
Mk6	1,322,479	1,077,697	823	17,973	28,639,825	4,035,054	261,231	2,655,450	1,410,063	2,023,905	2,018,872	56.63
Mk7	22,401	103,144	11,515	0	14,989,115	186,026	11,342	197,717	434,446	34,475	1,020,520	22.16
Mk9	144,201	39,715	0	75	5,144,087	25,340	84	16,861	434,096	8,657	2,595,403	10.96
Other	385,864	21,683	30	226	4,087,668	933,648	14,091	528540	41,677	220,133	0	8.12
Plastic	15	0	0	0	4,745	0	0	0	975	0	28,392	0.04
Total (%)	2.58	1.62	0.02	0.02	70.49	6.81	0.38	4.45	3.16	2.99	7.48	

package design and deployment strategy. From a design perspective, each package type may be used for both apples and pears; however, due to practical limitations such as retail shelf layout and limitation of package weight and regional market preferences, certain package types are clearly more favoured for a certain fruit type. For instance, the Central Europe (C/Europe) and United Kingdom regions were responsible for 95 % of the Mk7 and Mk9 carton exports, while there was a relatively even distribution for the rest of the package designs. This high preference can be explained by many of the supermarkets in these areas making use of retail shelves specifically designed to accommodate the Mk7 and Mk9 (600 × 400 mm).

The two primary telescopic package types are Mk4 and Mk6 cartons, both designed to facilitate high density packaging of pome fruit. These two cartons were used for 48 and 4 % of total apple exports, respectively, and < 1 and 57 % of pear exports, respectively. This significant difference in carton use can be attributed to the higher density of pears (approx. 1.05 kg/L) compared to apples (approx. 0.86 kg/L). Although the Mk4 offers a higher packing density of fruit, the average mass of packed fruit is 18 kg of apples and 22 kg of pears. The large weight of a 22 kg carton is generally considered high for human lifting, resulting in more preference for 12 kg mini-MK6 pear cartons.

Similar observations were noted with the two most widely used 'Display cartons' (Mk7 and Mk9). The Mk7 package design, which represents 22 and < 1 % of total pear and apple export cartons is used primarily with a single tray of fruit. On the other hand, the Mk9 which has capacity for two trays represented 22 and 11 % of apple and pear carton exports, respectively. In addition, the higher height of Mk9 package allows for convenient packaging of thrift bags and punnets, and hence making the package design popular for handling and marketing of both apples and pears.

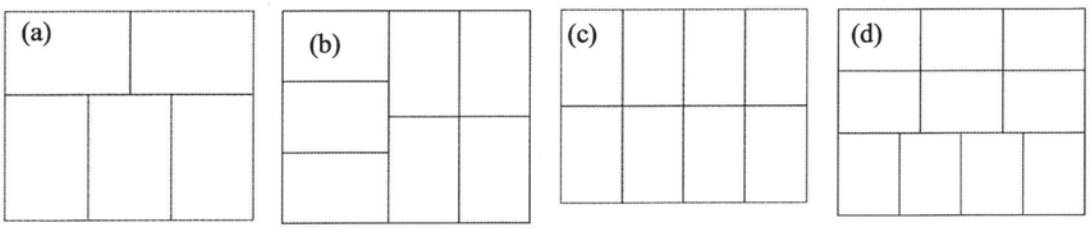
Packaging Formats and Types

The survey identified four stack configurations as shown in **Fig. 1**. These configurations are based on the standard 1.2 × 1.0 m export pallet and the 1.2 × 0.9 m (**Fig. 1c**) pallet which is used predominantly in the local market.

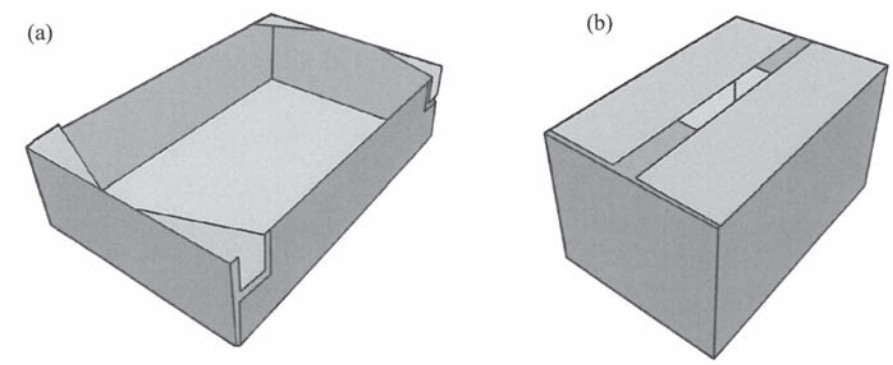
There are several companies in the Western Cape Province (South Africa) producing numerous cartons designs, which is largely a market-driven process. Overseas and local markets will place an order for specific type of fruit packed inside specific package design to meet the requirements for their handling systems and marketing logistics, including transportation using freight containers.

Two major distinct carton de-

Fig. 1 Pallet stacking arrangements showing a) 5, b) 7, c) 8 and d) 10 cartons per layer



Figs. 2 and **3**-D outline of a) Display/ (0773-M) and b) Telescopic/ (0200-M/A) carton designs



signs were identified in the survey, namely the display (**Fig. 2a**) and the Telescopic designs (**Fig. 2b**). Telescopic cartons are commonly used for packaging of fruit in layers or bulk, allowing fruit to be repackaged or placed in a heap at the point of retail. Display cartons on the other hand, serve a communication function by allowing the whole package to be placed directly on the shelf at the point of retail. The construction of a fibreboard carton, irrespective of it size and ventilation can be described according to 'The International Fibreboard Class Code' (IFCC) document, which uses a simple code to describe the construction design (FEFCO & ESBO, 2007). Under the IFCC fibreboard box categories the construction of display cartons follows the 'Ready-glued cases' category (code 0773-M design) and 'Folder-type' (code 0432-M design). The telescopic cartons follow the 'Telescope-type boxes' category (code 0200-M/A). Within the two categories, a total of twenty carton designs were identified during the survey, and on closer examination, there were further classified into eleven distinct types of carton as shown in **Table 3**.

The Mark 7 (Mk7) and Mark 9 (Mk9) cartons are very similar in shape and vent design. However, the primary difference is that Mk7 is designed for a single layer of fruit while Mk9 is designed to hold a double layer of fruit. The additional height of the Mk9 carton (39 > 91 mm) allows for the use of internal packaging, such as thrift bags and punnets, which make it popular in the export of both apples and pears, whereas the Mk7 is almost entirely used for pear exports.

The Mini-Mk9 and Econo-D cartons are both display carton designs, which are used primarily on the local market, although a small number of exports do occur. The Mini-Mk9 carton is frequently used at local convenience stores near motor-vehicle refuelling stations. Trays are

Table 3 Generalizeddesigncharacteristicsofappleandpearcartons

		Open Display						Telescopic					
Carton name		Micro-D	Mini-Mk9	Mark 9	Mark 7	Econo-D	Econo-T	Bushel	Mark 6	Mark 4	Jumble	Mini-T
Pack code (part of GTIN)		A02C, B02C, C02C	M05D, M06D	A12T, A12D, B12D,C12D	A06D, B06T, B06D, C06T, C06D	E12D, T12D	E12T, T12T	M22T	M12T	M18T, P15T	J11T, J10T	M07T
International Fibreboard class code		0432-M	0773-M	0773-M	0773-M	0773-M	0200-M/A	0200-M/A	0200-M/A	0200-M/A	0200-M/A	0200-M/A
Dimensions (mm)	Length	400	400	600	600	460	460	500	400	500	350	400
	Breadth	300	300	400	400	300	300	330	300	330	300	300
	Height	79	150	139	91	229	238	339	220-275	287	228	142
Length-wise surface (mm^2)	Total area	31,600	60,000	83,100	54,600	105,340	109,480	169,500	97,200	143,625	79,625	56,800
	Vent area	3,214	2,094	3,721	5,599	1,145	3,680	5,073	5,163	5,448	3,520	5,880
	Vent area (%)	10.17	3.49	4.48	10.25	1.09	3.36	2.99	5.31	3.79	4.42	10.35
Breadth-wise surface (mm^2)	Total area	23,700	45,000	55,400	36,400	68,700	71,400	111,870	72,900	94,793	68,250	42,600
	Vent Area	220	0	49	0	2,193	1,473	3,598	2,050	3,758	2,086	2,880
	Vent area (%)	0.93	0.00	0.09	0.00	3.19	2.06	3.22	2.81	3.96	3.06	6.76
Total carton vent area (%)		6.21	1.99	2.72	6.15	1.92	2.85	3.08	4.24	3.86	3.79	8.81
Internal packaging (number of trays plus other materials)		1	2 or 2 +Poly-liner, or thrift-bags or punnets	2 or 2+Poly-liner or thrift-bags or punnets	1 or 1+Poly-liner or thrift-bags or punnets	thrift-bags	thrift-bags	6 or 6+Poly-liner	4 or 4+Poly-lineror Thrift bags	4 or 4+Poly-liner	Loose	2 or 2+Poly-liner,
Cartons per a pallet layer		10	10	5	5	8	8	7	10	7	10	10

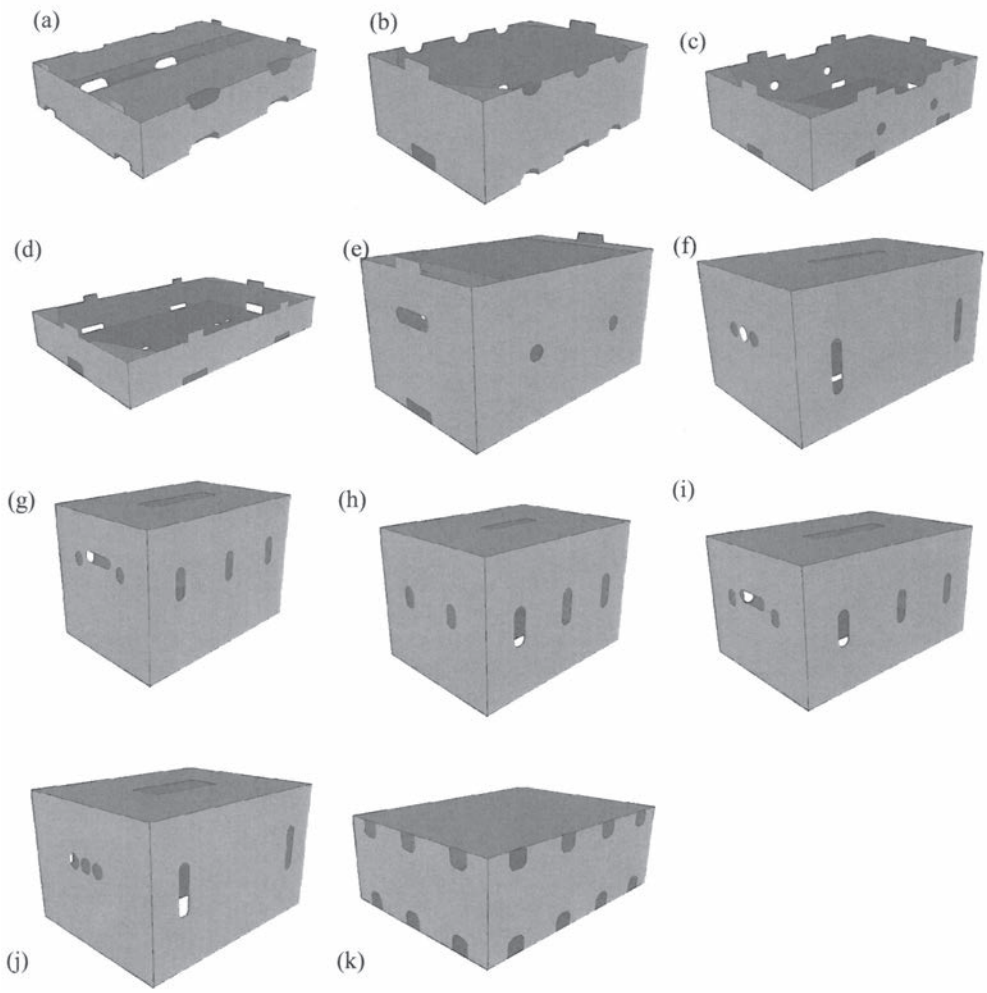
regularly used in the Mini-Mk9 to enable consumer purchase of individual fruit as a 'snack food'.

The Econo-D and Econo-T have been designed to accommodate the different transport requirements of the local South African market. This entails the use of thinner corrugated fibreboard and a different package size to accommodate different pallet sizes and smaller transport distances. According to industry experience, these characteristics reduce the resistance of the palletized stack to compression damage. However, given the significantly shorter transport duration and the competitive nature of the local market for low cost fruit, the reduced strength of the carton is validated as it might result in a situation where a minor decrease in quality is acceptable if there is a significant reduction in cost. The Econo-T is the telescopic version of the Econo-D carton. The Econo-T design is also used predominantly with thrift-bags of fruit in the local market.

The Mark 11 (Mk11) and Bushel package designs are used for high density packaging of pome fruit, with two and six trays, respectively, while the Mk4 and Mk6 designs hold four trays of fruit. The Mini-T cartons are telescopic designs used in conjunction with two trays and sometimes with a polyliner bag. The Mini-T is half the height (and capacity) of the Mk6 carton and is used for both apple and pear export. This design offers a larger degree of physical protection to the fruit by making use of a larger package-to-fruit ratio of packaging than the Mk6 and Mk4 cartons.

The jumble carton is a high density bulk packaging used primarily for apples where fruit are packed loose inside the carton. The carton is almost exclusively used for the transport of lower grade apples in the local informal market, as well as for export to other African countries. The reduction in packaging size reduces the overall packaging cost. **Table 3** shows the geometrical size and ventilation area of the different types of packaging.

Fig. 3 D outlines of a) Micro-D, b) Mini-Mark9, c) Mark9, d) Mark 7-D, e) Econo-D, f) Econo-T, g) Bushel, h) Mark 6, i) Mark 4, j) Jumble and k) Mini-T



Internal Packages

Several types of internal packaging are used in the pome fruit industry, resulting in multi-scale ventilated packaging. Internal packaging can play both an aesthetic and functional role in the postharvest handling of fruit. The tray was the most commonly observed internal packaging and is either produced from polyethylene or pulp paper and mostly used to hold fruit inside telescopic cartons (Holt & Schoorl, 1984).

Polyliner bags are also used inside apple and pear, by packaging them inside the carton surrounding the trays and fruit. Polyliner bags are used in Telescopic cartons and Display cartons in combination with trays. The primary functions of polyliner bags are to modifying the moisture, oxygen, carbon dioxide or volatile gas concentrations surrounding fruit (Shorter, Scott, Ward, &

Best, 1992; Geeson, Genge, & Sharples, 1994; Linke & Geyer, 2013). Polyliner bags also present a physical barrier between the fruit and pathogens in the surrounding air. Three predominant film thicknesses found were 20, 37.5 and 60 µm.

Thrift bags and punnets are also used in pome fruit packaging. These packages allow several fruit to be placed inside a bag or punnet and then placed into a carton to facilitate handling and retailing marketing (Vigneault *et al*., 2009). In addition to the above types of inner packaging, shrivel sheets, riffled paper, sponge sheets, jiffy pads and bubble pack sheets are often used as mechanical insulators between fruit and the carton top wall to prevent physical damage to fruit from fruit-carton contact. Bubble pack sheets were the most commonly observed type used in pome packaging.

The effects of multi-scale packaging on fruit quality and cooling rate have been reported. For instance, (Ngcobo, Delele, Opara, Zietsman, & Meyer, 2012) showed that the presence of internal packaging (such as polyliner bags) in multi-scale packages of table grapes restricted airflow through the package during forced air cooling (FAC). The results showed that polyliner bags contributed to 40 and 83 % of the total pressure drop of package for micro-perforated and non-perforated liner films, respectively. In addition, the use of bunch carry bags (which are similar to thrift bags) accounted for 2.43 to 12.58 % of the total pressure drop.

Ventilation Characteristics

The ventilation characteristics of the eleven major carton types identified are displayed in Table 3. Mk4, Mk6, Mk11 and Bushel cartons have oblong vent holes in accordance with the recommendation by Han & Park, (2007). The ventilation configuration of Mini-T, however, follows the recommendation of (Thompson, Mitchell, & Kasmire, 2002) that 5 to 6 % side wall ventilation should be used as a compromise between mechanical strength and airflow penetration. The, Econo-T, Econo-D and Jumble cartons also have mainly oblong vents; however, many side walls were found to have circular shape holes, usually with a diameter of 26 mm. Finally, the Mk7 and Mk9 cartons, which are relatively low in depth, have circular holes (26 mm) and/or large cavities along the top edge of the carton (width). Several slot holes were also present, although during stacking, these would be obstructed by the corresponding tabs of the carton below.

Many of the cartons are stacked in configurations which allow both the carton length and breadth to align perpendicular to the direction of airflow (**Fig. 1**), highlighting the importance of ensuring that both sides of the carton are ventilated. **Table 3** shows that total carton ventilation varied considerably between 1.92 % (Econo-D, open display) and 8.81 % (Mini-T, telescopic). Mean side wall (length-wise) ventilation area 5.04 and 5.90 %, respectively, for telescopic and display designs, which is within the range recommended by Thompson *et al.* (2002). The Mini-Mk9, Mk7 and Mk9 packages have no ventilation along the breadth (shortest side of the carton). This resulted in lower mean carton breadth side vent area of 0.84% for display cartons compared with telescopic designs (3.65 %).

Due to the different stacking configurations, these cartons will not have complete ventilation alignment in stacking types a, b and d (**Fig. 1**) in both directions (length and width). The lack of ventilation alignment will result in large pressure drops (Vigneault, Markarian, & Goyette, 2004) and poor airflow rates during forced air cooling (FAC) and therefore contributing to ineffective precooling of fruit (Kader, 2002). Computational fluid dynamic modelling of airflow, heat and mass transfer inside ventilated multi-scale packaging of spherical objects showed the stacking patterns have considerable influence on airflow patterns and fruit cooling rates (Delele *et al*., 2008).

De Castro, Vigneault, & Cortez (2005b) recommended an open area of 8-16 % for effective cooling and Kader (2002) recommended 5-6 %. None of the commonly used pome fruit cartons was within the range of ventilation area recommended by de Castro *et al.* (2005a), while only the Mini-T has ventilation area within the range recommended by Kader (2002). It should be noted, however, that these recommended vent open areas reported in the literature were based on experimental analysis of specific package designs for specific types of fruit. This makes it difficult to compare different designs used to handle different types of fruit in different supply chains. More research is required in this area, including the application of recent advances in computational fluid dynamics and finite element modelling (Pathare *et al*., 2012).

Conclusions

Appropriate ventilated packaging is an essential tool in the process of postharvest management of fresh horticultural produce such as fruit. In addition, good temperature control in the cold chain is vital to maintain fruit quality and increase the duration of fruit storage times in postharvest systems. The survey of ventilated package geometrical designs in South Africa showed that eleven corrugated fibreboard carton designs are predominantly used in commercial handling and marketing of pome fruit. Furthermore, these carton designs can be packaged with several types of internal packaging, including trays, polyethylene liner bags, thrift bags and punnets.

The different types of package used to handle apples and pears can be divided into ‘Display’ and ‘Tele-

scopic' designs. Display cartons, through the use of internal packaging such as thrift bags and punnets, offer retail ready pre-packaged fruit, and therefore add additional marketing value to the carton. Telescopic cartons, on the other hand, offer high density fruit packaging during shipping; however, they usually require repacking at the retailer. For the telescopic carton designs, the Mk4 made up 48 % of apple cartons and Mk6 design accounted for 58 % of pear cartons used in fruit export. For display cartons, 22 % of apple and pear export cartons used were Mk9 and Mk7, respectively. The ventilation area per carton varied between 1.92 and 8.81 %., with average of 3.80 and 4.44 % for display and telescopic designs, respectively. The practical implications of these variable vent characteristics on carton cooling and mechanical performance are not well known and no evidence of a standardised approach to optimise vent design was found during the study. More research is recommended in this area.

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