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Research Paper

The role of horticultural carton vent hole design on cooling efficiency and compression strength: A multi-parameter approach

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ABSTRACT

Forced-air cooling (FAC) is used to rapidly remove the field heat of horticultural produce to better preserve quality. Cartons are ventilated to promote uniform cooling of the packed produce and to minimise energy used by precooler fans. The resulting cooling efficiency is influenced by the area and configuration of carton vent holes. However, placing vent holes also reduces the carton compression strength, which requires reinforcement using additional fibreboard, thereby increasing carton manufacturing costs. This study, therefore, applied a multi-parameter evaluation approach to assess four carton designs, each for three vent hole areas and three corrugated fibreboard grades. Computational fluid dynamics (CFD) was used to evaluate airflow resistance, cooling rate, uniformity and package related energy consumption. Experiments were used to quantify box compression strength. Results of mechanical strength evaluation showed a negative linear relationship between carton strength and vent hole area. The effect of vent hole configuration on compression strength was dependent on the corrugated fibreboard grade. For cartons packed using trays, the Multivent vent hole design used 58% less FAC energy and also significantly improved cooling uniformity compared to the Standard vent design. The significant improvement in FAC energy efficiency, therefore, enables the Multivent to match or improve the compression strength and FAC energy efficiency of the Standard vent design, by using a considerably smaller ventilation area. This study thus demonstrates the importance of incorporating a multi-parameter approach in developing improved packaging with optimised vent hole designs.

1. Introduction

With rising world population predicted to reach 9.1 billion by 2050, reducing high incidence of postharvest losses, which is estimated at 15–30% globally, is a necessary step in ensuring future food security (FAO, 2009; Opara, 2010; Munhuweyi et al., 2016). Temperature mismanagement and physical damage are considered the most common causes of postharvest losses of fresh fruit (Kader, 2002; Opara and Pathare, 2014) and can be minimised by using packaging and cold chain facilities more efficiently (Gustavsson et al., 2011; Opara and Mditshwa, 2013; Pathare and Opara, 2014). Future packaging will thus be expected to play a greater role in facilitating temperature regulation during precooling processes, as well as in protecting produce from physical damage, such as bruising or abrasion (Thompson et al., 2008; Defraeye et al., 2015). The ventilation design of horticultural packaging, must therefore take into consideration multiple performance parameters so that it functions efficiently across all areas of the cold chain.

Carton are commonly palletised to simplify handling and to improve packing density during precooling, transport and storage. Packaging containers and pallet structures create barriers between the fruit and the surrounding refrigerated air, which limits cooling and quality preservation. Air penetration is therefore enhanced by adding vent holes to the cartons. Fruit cooling rate and uniformity are typically a function of the airflow rate and cooling air

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temperature, as well as the resulting airflow distribution in the carton. These aspects are determined by the produce-packaging system, including vent holes, fruit size, fruit shape, packing configuration and internal packaging (van der Sman, 2002; Anderson et al., 2004; Han et al., 2015; O'sullivan et al., 2016). Conversely, vent holes must be added cautiously as they reduce carton mechanical strength and, therefore, increase susceptibility to mechanical failure, particularly when palletised. Several studies have identified improved vent hole designs for higher mechanical strength using various strategies (Singh et al., 2008; Frank et al., 2010). Jinkarn et al. (2006) examined circular and oblong (elliptical) vent holes and determined that circular vent holes placed near the wall centre reduced mechanical strength less than other designs. Han and Park (2007) also examined circular and oblong vent holes; however, the authors showed that vertical oblong vent holes were preferable to other designs, which is consistent with designs used in commercial environments (Berry et al., 2015).

Vent hole design has been investigated predominantly in the context of forced-air cooling (FAC), with the aim of improving air penetration into the stack of cartons. This is essential to facilitate rapid and uniform fruit cooling during FAC, without creating conditions that induce fruit chilling injury (Alvarez and Flick, 1999; Kader, 2002; Sevillano et al., 2009). FAC entails a fan system that draws refrigerated air horizontally through pallets and cools the fruit convectively. FAC should also be designed so that the desired temperatures are reached within fixed time frames, to avoid delays in the handling procedure. Prolonged FAC can negatively influence cold chain efficiency and can unnecessarily extend periods that uncooled fruit spend queuing for FAC (Kader, 2002).

Another important aspect in FAC is fan energy consumption, which is a function of the pallet's resistance to airflow (RTA), the

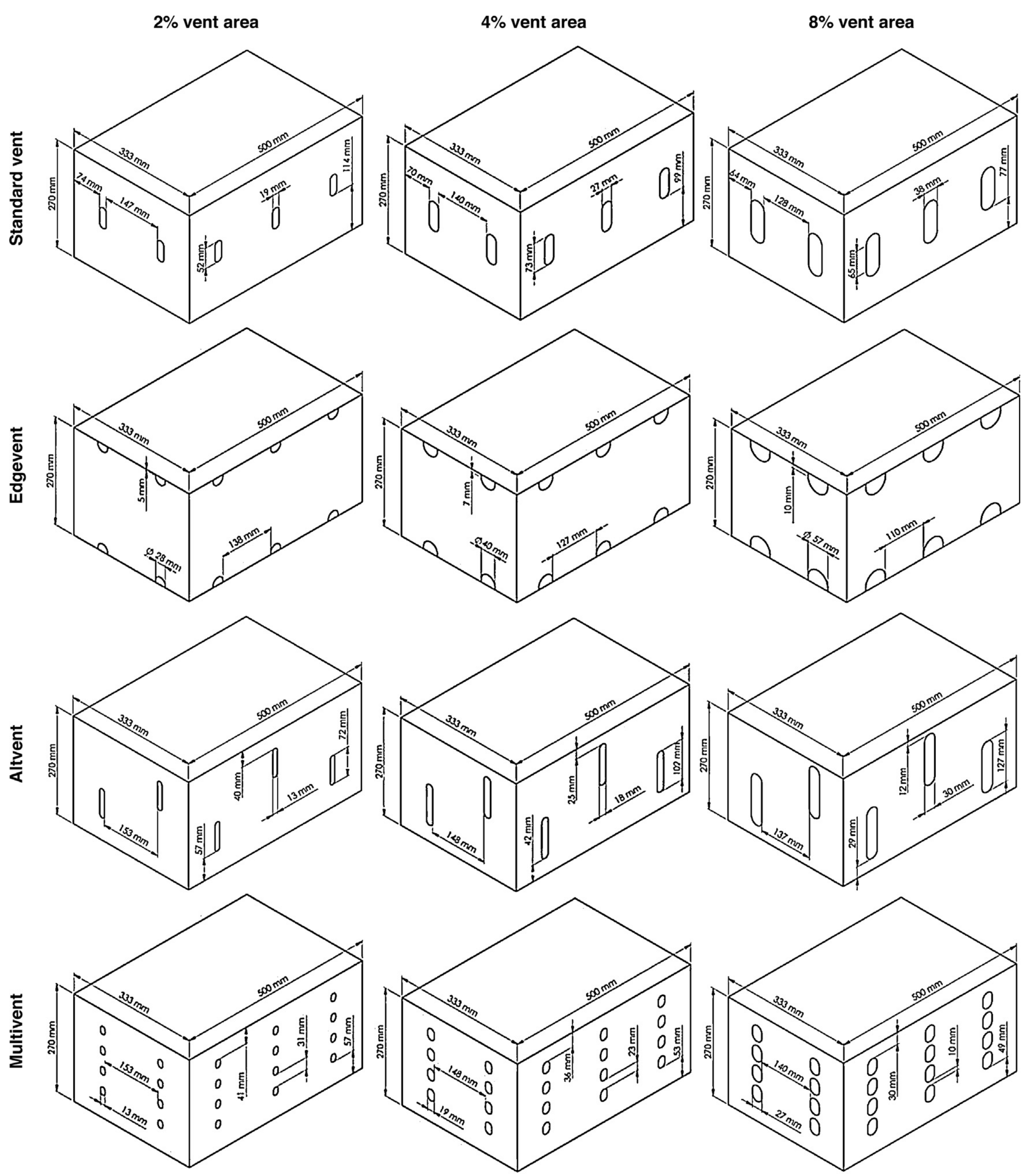

Fig. 1. Geometry and diagram of the corrugated fibreboard cartons: Standard vent, Edgevent, Altvent and Multivent.