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Review

Structural design of corrugated boxes for horticultural produce: A review

Pankaj B. Pathare [a,b], *Umezuruike Linus Opara* [a,b,*]

[a] *Postharvest Technology Research Laboratory, South African Research Chair in Postharvest Technology, Department of Horticultural Science, Faculty of AgriSciences, Stellenbosch University, South Africa*

[b] *Postharvest Technology Research Laboratory, South African Research Chair in Postharvest Technology, Department of Food Science, Faculty of AgriSciences, Stellenbosch University, South Africa*

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Corrugated boxes are used extensively for transporting and storing fresh produce in the horticultural industry. These boxes protect their contents from mechanical damage due to drops, impacts, vibration and compression loads. The analysis and prediction of the stacking compression load capacity of corrugated boxes is important to study the response of existing packaging to mechanical stress or to design new boxes to meet postharvest handling conditions. Good design of vented packaging is important in optimising the cooling and ventilation uniformity, minimising quality deterioration of packed produce and maintaining the mechanical integrity of the box. Various experimental and modelling tools are used to investigate the design and mechanical performance of packaging. Experimental studies on mechanical performance of packaging include compression, impact and vibration analysis. Finite element analysis and simulation is useful for study and structural design of ventilated corrugated packaging, considering the shape, location and size of the vent. Advances in information and communication technologies offer new prospects for development of user-friendly software toward integrated design and performance analysis of fresh produce packaging.

1. Introduction

Packaging plays a critical role in the postharvest handling and distribution of fresh and processed food and other biomaterials (Opara, 2011; Pathare, Opara, Vigneault, Delele, & Al-Said, 2012). Packaging has many other important functions, such as protecting the packaged goods from hazards including contamination in the distribution environment, facilitating transportation and storing of products, and carrying printed information and graphics (Hägglund & Carlsson, 2011). Packaging is one of the most important steps in the long and complicated journey of fresh horticultural produce from grower to consumer (Boyette, Sanders, & Rutledge, 1996).

The types of packaging used for fresh horticultural produce handling include wood crates, corrugated shipping boxes, polymeric films pouches, bags, baskets, crates, trays, paper sheets, pouches, etc (Pascall, 2010). Boxes have to withstand

* *Corresponding author*. Postharvest Technology Research Laboratory, South African Research Chair in Postharvest Technology, Department of Horticultural Science, Faculty of AgriSciences, Stellenbosch University, South Africa. Tel.: +27 21 808 4064; fax: +27 21 808 3743.

E-mail address: opara@sun.ac.za (U.L. Opara).

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significant compression loading conditions during carriage and storage (Viguié et al. 2011) and corrugated boxes are well known for their good stacking strength (when dry), easy availability and low cost (Twede & Harte, 2003). Corrugated board is the dominant packaging material in the horticultural industry and has many advantages such as low mass (saves money when transporting), customised easily for the purpose, strong and stiff compared to its mass, easy to handle, easy to print and recyclable (Allansson & Svärd, 2001). The strength and serviceability of corrugated paperboard have improved over the years. Paper and board (38%) is the most used consumer packaging, followed by plastic (30%) (World Packaging Organization, 2008). Corrugated boxes are predominantly used for export while reusable plastic containers (RPC) are used for the domestic market (Jarimopas, Sirisomboon, Sothomwit, & Terdwongworaku, 2007). The use of bamboo baskets is common in many developing countries such as India; however, due to the geometrical design, baskets cannot be successfully stacked or be used for long distance transport in trucks (Ladanyia, 2008).

It is important to have a clear understanding of the wide range of packaging options available as packing methods and packaging materials contribute a significant cost to the produce industry (Boyette et al., 1996). Cost savings could be made by reducing the quantity of material used in the box, provided that adequate compression strength can be maintained. Design of corrugated boxes should include optimal combination of raw materials, optimal selection of prism type, overall box design optimisation, and the packaging cost (Chen, Zhang, & Sun, 2011). The objective of fresh horticultural packaging design is to reduce mechanical damage to produce during the distribution process and improve overall packaging performance. Cool storage and transport conditions for fresh horticultural produce provide one of the most demanding environments for corrugated boxes. Conventionally, a product reliability test to prevent impact-induced damage is carried out by 'design – prototype – test – redesign' procedure which is costly and time consuming. Numerical modelling of the product and its interaction with packaging provides an efficient methodology to predict the structural strength during impact (Djilali Hammou, Minh Duong, Abbès, Makhlouf, & Guo, 2012). Finite element analysis (FEA) simulation offers a useful tool for the mechanical design of ventilated packaging, taking into account factors such as the shape, location and size of ventilated opening. Application of FEA to predict possible failures reduces the need for numerous and expensive experimental tests during the design stage (Djilali Hammou et al., 2012).

The traditional functions of packaging applicable to fresh horticultural produce are containment, display, maintenance of quality and prevention of mechanical damage during handling and shipping, and facilitation of transport and marketing. High incidence of mechanical damage is a major source of postharvest losses in the fresh produce industry and hence corrugated board packaging is widely used for bulk handling and marketing of fresh horticultural produce (Opara & Pathare, 2014). The present article provides an overview of the application of corrugated boxes in the horticultural industry, and discusses the experimental and modelling approaches used to investigate the structural design and performance analysis packaging.

2. Applications of corrugated boxes for horticultural produce

Fresh produce boxes are designed to facilitate postharvest operations such as precooling, protect from environmental and physical damage, reduce the loss of produce shelf life and meet the specific fresh produce handling requirements (Vigneault, Thompson, & Wu, 2009). Several parameters may be used to assess the quality of a packaging design including compression strength, stiffness, tearing resistance, tensile strength, water absorption capacity and product safety. Corrugated board has been reported to have good properties as a material packaging which reduced mechanical damage of apple (Jarimopas, Toomsaengtong, Singh, Singh, & Sothornvit, 2007) and mangosteen (Darmawati, Yulianti, Salokhe, & Soni, 2009; Sutrisno, Sugiyono, & Edris, 2010). The ease of recyclability along with its high strength to weight ratio and high printability has made corrugated packages a prime choice for fresh produce packaging.

Corrugated board is an orthotropic sandwich structure in which a central paper (corrugated medium) has been formed (using heat, adhesive and pressure) in a corrugated (i.e. fluted) shape on one or two flat papers (called liners) (Fig. 1). The principal directions are the machine direction (MD), the cross-machine direction (CD), and the thickness direction (ZD). Due to the distribution of the fibres during forming of the sheet and the different drying strains in MD and CD, the MD is usually the stiffest and strongest direction (Stenberg, Fellers, & Östlund, 2001). Corrugated board has been referred to by different terms such as corrugate, corrugated and corrugated fibreboard, and is manufactured in many different styles and masses (Boyette, Sanders, & Rutledge, 2000). The sheet can be modified to reduce mass or increase strength and protection from the external elements by flute size variations or adding flute layers. The flutes act like arches, resisting flat crush, to provide cushioning trapped air, and give some insulation properties (Twede & Selke, 2005). Corrugated boards may be graded by the size of the fluted medium and are commonly classified based on the number of flutes m^{-1} (namely A, B, C, E, F or microflutes) (Hägglund & Carlsson, 2011). The most common way to specify a corrugated board is by basic mass or grammage (mass per unit area) where higher basic mass results in stiffer and stronger board. Bending stiffness or flexural rigidity is also an important attribute of a corrugated board (Luo, Suhling, & Laufenberg, 1995).

Ventilated packaging has been widely adopted for fresh produce storage and marketing, partly due to the ability to promote rapid, uniform and efficient cooling process (de Castro,

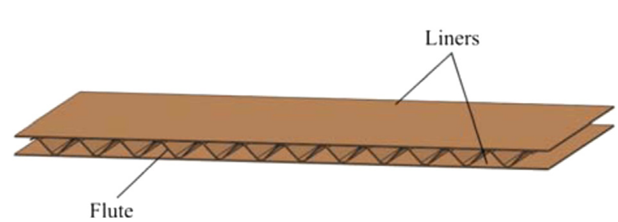

Fig. 1 – Structure of the corrugated board (Gospodinov, Stefanov, & Hadjiiski, 2011).