

Review

The role of wrapping in securing food system: Adding worth to food products and reducing fatalities and waste

Kenny Ray, Onami Elam and Mushove Thabo

Department of Biological Sciences, College of Natural And Applied Sciences, University of Johannesburg,
Johannesburg, South Africa.

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Packaging is an essential component of the food system, assuring the safe handling and delivery of fresh and processed food products from the point of production to the end user. Technological developments in packaging offer new prospects to reduce losses, maintain quality, add value and extend shelf-life of agricultural produce and consequently secure the food system. The objective of this review is to highlight the contributions of packaging in securing the food system by maintain quality and reducing food losses and waste. The review also discusses some of the novel and emerging packaging technologies that have revolutionized the way we handle and package food to meet the increasing consumer demand for consistent supply of high quality, safe and nutritious products.

Key words: Food system, food products, packaging, waste, plastic.

INTRODUCTION

Maintaining food quality and improving safety, and reducing postharvest losses waste are key objectives of a sustainable food system. High incidence of postharvest losses and waste pose a major problem in the food industry and world at large. An estimated 1.3 billion tonnes of food is wasted annually in production, distribution, and homes (Quested et al., 2011). Reports from developed countries such as Britain, Sweden and USA have indicated that almost one third of purchased food is wasted at food service institutions and households (Wikström and Williams, 2010). In addition to the effects of a wide range of socio-economic, climatic and environmental factors, the loss and wastage of already harvested food is a major contributor to food and nutritional insecurity. Moreover, reducing food loss and preventing waste also has environmental benefits given that each tonne of prevented food waste contributes to avoiding 4.2 tonnes of carbon dioxide emissions that

would have been associated with the waste (Quested et al., 2011).

In the early days of agriculture, leaves and animal skin were used as packaging materials to carry food over short distances and to secure them for later use. In modern food systems, the principal functions of packaging have widened to include containment, protection, communication and convenience. Paine and Paine (1992) noted that "to ensure delivery, the package must at least provide information as to the address of recipient, describe the product and perhaps describe how to handle the package and use the product." Despite the overriding importance of packaging in maintaining quality and wholesomeness and facilitating the movement of food along the value chain, there is continuing debate on the amount of packaging used in the food industry in relation to packaging waste the environmental impacts, as well as the role of packaging in reducing food losses

*Corresponding author. E-mail: Kenny_ray@gmail.com

and waste (Opara, 2011).

Inappropriate processing and packaging (or lack of these) can contribute to 25 to 50% food loss, especially in developing countries. About 10% of fruit and vegetables shipped to European Union are discarded due to unacceptable quality and spoilage (World Packaging Organization, 2008). These high levels of postharvest loss and waste suggest that food production is only half the battle to feed the world (Opara, 2011). Examining the role of packaging in reducing postharvest food losses and waste is particularly important given that packaging also contributes to municipal waste after completing its function of protecting the contents. The need to handle and dispose large quantities of packaging after utilising the food contents, therefore, constantly puts packaging waste in bad light in public discussion about waste, often ignoring the critical role that packaging plays in securing the food system.

The objective of this paper, therefore, is to highlight the role of packaging in the food industry with particular attention to the impacts of packaging in maintaining product quality and safety and reducing the incidence of postharvest food losses and waste. Recent advances in smart and intelligent packaging designed to minimise some of the negative impacts of packaging on the environment and food waste are highlighted. The environmental impacts of food packaging are examined and measures to reduce packaging waste are discussed. In the next section, we highlight the different types of materials and formats used in food packaging.

Types of packaging materials and formats used in the food industry

A wide range of packaging materials and packaging formats are used in the fresh and processed food industry to handle, store, and distribute fresh and processed food products, from farm to the consumer. Different types of materials such as glass, plastic, metal, cardboard are used for making packaging containers and the material used depends on the nature of the food product because different packaging materials possess a range of performance characteristics that exert significant impacts on shelf-life (Robertson, 2011). Bottles and glass jars are often used for packaging liquid food stuff while solid food products are mostly packed on plastics and cardboards. Processed fruit and vegetables are usually packed in airtight metal containers to prevent oxygen transmission that might lead to spoilage of the product through microbial growth and oxidation of lipids (Robertson, 2010). According to the World Packaging Organization (2008), the most important consumer packaging are made of paper and board (38%), followed by plastic (30%) with rigid plastics alone taking an 18% share, metal (19%), glass (8%), and others (5%). Moreover, approximately 70% of overall consumer packaging are used in food industry where 48% of all the

packaging are made from paperboard.

Plastic

Historically, packaging was used primarily to prevent food contamination with unwanted objects. However, consumer demand for desirable food quality has led to a surge in packaging innovation. For instance, Cha and Chinnan (2004) noted the increasing use of plastic films in food packaging, which combines the biophysical properties of plastic films with biopolymer coatings to maintain the nutritional and sensory quality of the product. Using plastic as packaging material also offers marketing advantage. Unlike metal and aluminium packaging materials, harnessing the transparency of film packaging for product visibility is now widely practised, enabling consumers to assess the visual quality of the product prior to purchase. However, the variable permeability to light, gases and vapours of plastics is a major drawback. The various kinds of plastic films include low density polyethylene (LDPE), laminated aluminium foil (LAF), high density polyethylene (HDPE), polypropylene (PP), polyethylene (PE).

Paper and cardboard

Paper and cardboard are made from cellulose fibres derived from wood and plant fibres using sulphate and sulphite (Robertson, 2011). The poor barrier properties of plain paper makes it unsuitable for long time storage. Protective properties of paper are usually improved by coating, laminating or filled with waxes and resins. Paper and cardboard are widely used in corrugated boxes, milk cartons, sacks, and paper plates. Packaging material based on paper has an advantage due to its high recyclability at relatively low cost. Paperboard packaging such as carton are the most widely used packaging in the horticultural industry. For horticultural food products such as fruit and vegetables which remain alive after harvest (Figure 1), the use of ventilated packaging is essential to facilitate the delivery of cold air to produce inside the packaging during precooling and refrigerated storage. The design challenge is to balance the cold chain requirements for optimum airflow while maintaining the mechanical integrity of the package and produce. Given that the marketability of fresh produce is reduced when precooling is delayed (Figure 2), resource-efficient package design for optimum cooling without adverse effects on produce quality are essential for cost-effective postharvest handling and marketing of fresh horticultural foods.

Metal

The good physical protection and recyclability of metal is

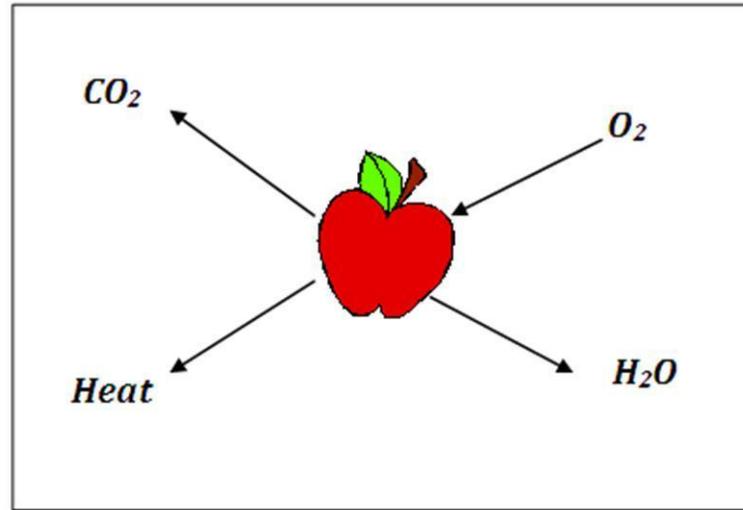


Figure 1. Fresh foods such as fruit and vegetables are alive and continue to respire after harvest. Reducing the respiration rate and reducing the heat produced through efficient airflow inside ventilated packaging is important in maintaining product quality.

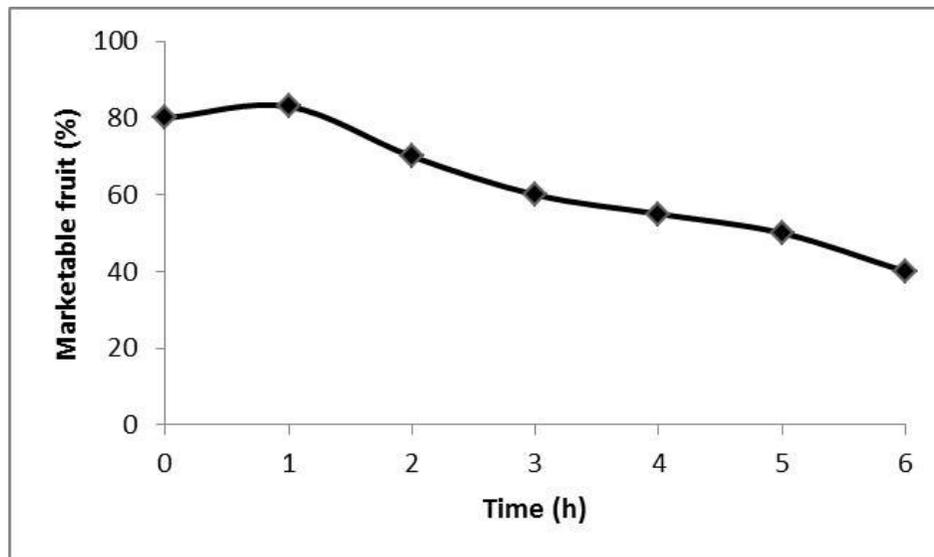


Figure 2. The effect of delay on precooling of horticultural produce (Adapted from Brosnan and Sun, 2001).

widely preferred in many food applications. Aluminium and steel are 2 metals predominately used in packaging (Marsh and Bugusu, 2007). Aluminium is commonly used in making cans, foil, and laminated paper. Carbonated beverages and seafood are often packed on aluminium packaging material. The high cost of aluminium compared to other metals is the main disadvantage of using it in food packaging systems. Steel packaging material is often used to make cans for drinks and processed foods such as beans and peas. The high mechanical strength and low weight of steel makes it

relatively easy to store and ship food (Marsh and Bugusu, 2007). Steel can be recycled many times without quality loss and its cost is significantly lower than aluminium hence it's highly used in packaging systems.

Glass

Glass is another common packaging material which dates back to 3000 BC (Marsh and Bugusu, 2007) and is used mostly for packaging processed foods especially

Table 1. Common packaging formats used for different products.

Packaging formats	Example of produce
Paperboard cartons	Fresh produce (apple, strawberry)
Polyethylene-laminated cartons	Processed produce (orange juice)
Wooden box	Fresh produce (strawberry)
Tetra recart carton	Processed produce (meat)
Tetra wedge package	Processed produce (meat)
Can	Processed food (minimally processed tomato pulp)
Glass bottle	Minimally processed food (tomato sauce, orange juice)
Plastic bottle	Processed food (citrus juice)

where moisture and oxygen barrier is of great importance. Carbonated beverage drinks contain dissolved carbon dioxide creating pressure within the package, and glass is often the suitable packaging capable of withstanding carbon dioxide pressure. Moreover, the odourless and static chemical property of glass that ensures unimpaired taste and flavour of the contents makes it advantageous for food packaging (Marsh and Bugusu, 2007). The reusability and recyclability of glass-based packaging material contribute to less negative impacts on the environment; the heavy weight of glass adds to the transportation costs of food products.

OTHER TYPES OF PACKAGING MATERIALS

Packaging can also be of mixed material. This kind of packaging may be resource and energy efficient than using a single material. However, the drawback of such packaging is the difficulty to recycle, which is attributed to the lack of infrastructure to separate the materials. New biodegradable, plant-based packaging materials are needed to combat environmental problems associated with such mixed packaging. Identification of biodegradable packaging materials and development of innovative methods to degrade plastic are thus needed.

Packaging formats used for different food products

Choosing the right format of packaging is important to meet the functions of packaging. There are some considerations for selecting appropriate packaging, including suitable structure and form, efficiency and disposal after use. While engineering and economic aspects of packaging performance are important, the environmental issues associated with packaging also need to be addressed when choosing packaging. Common packaging formats used in the food industry include paperboard cartons, wooden boxes, metal cans, glass, and plastic bottles (Table 1). For horticultural produce such as fruit, the packaging format may be

paperboard produced as single layer or multi-layer cartons and stacked into pallets or bulk bins made of wood or plastic (Figure 3).

Developments in package-food-environment interaction

Developments in sensors and information and communication technologies have enabled designers to impart desirable packaging attributes which promote greater interactions between the product and package as well as enable the consumer to make decisions about the quality and safety of the product contained in the package. The use of these highly instrumental packaging systems have various functions that are important in maintaining produce quality and safety as well providing other value-added services to the consumer.

Smart packaging

Smart packaging refers to an improved packaging system with functional attributes that add benefits to the food product and subsequently the consumers. Smart packaging uses an integrated approach with mechanical, chemical, and electrical driven-functions to ensure an improved usability of food products. Some of the prominent facets of smart packaging include use-by dates, usage of self-heating or self-cooling containers with electronic displays storage temperature, and nutritional information of the product (Mahalik and Nambiar, 2010).

Active packaging

Active packaging is categorized into active scavenging systems (absorbers) and active releasing systems (emitters) (de Kruift et al., 2002). Under scavenging packaging system, unwanted compounds such as oxygen, excessive moisture and ethylene which accelerate the spoilage process in foods are removed from the product. For instance, oxygen may cause off-

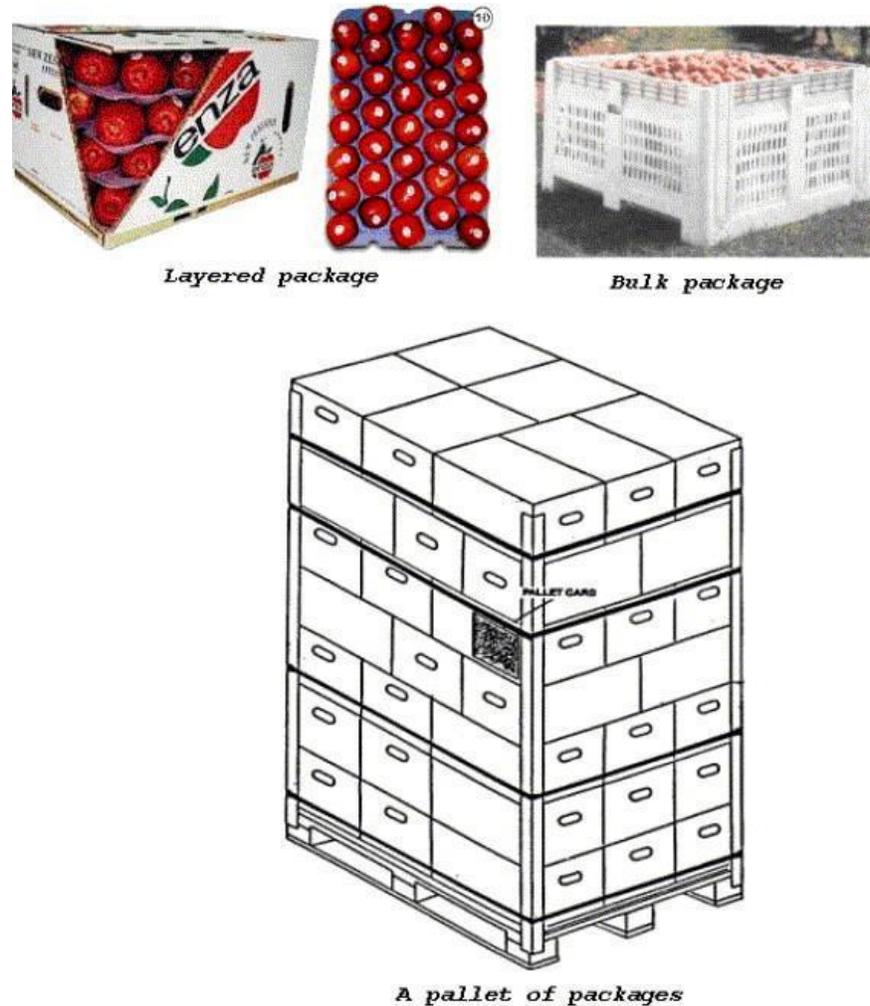


Figure 3. Different packaging formats used for handling fresh fruit such as apple (Opara, 2011).

flavours, nutrient loss (through oxidation) and colour changes; hence the usage of oxygen scavengers to maintain quality and extend shelf life of some food products (Berenzon and Saguy, 1998) (Figure 4). The moisture content of packed horticultural products should be controlled because high moisture content favours microbial growth. The softening of dry crispy food products such as biscuits and caking of coffee result from unregulated moisture content. Moisture controlling systems are often used to scavenge excess moisture that contributes to product quality loss. However, it is worth noting that excess moisture loss might impose lipid peroxidation and desiccation of packed products. It is therefore imperative to have a good understanding of product physiology, structure and composition when designing the packaging as food stability is closely linked to water activity. Active releasing packaging system is another aspect of active packaging and this involves the addition of beneficial agents to the package to preserve the quality of the content. Releasing packaging system

favours the addition of compounds such as carbon dioxide, moisture, preservatives and antioxidants into the package. Carbon dioxide releasing systems are also used to retard respiration of horticultural crops and subsequently prolong shelf-life. The main objective of active packaging, with both scavenging and releasing systems, is ensuring exceptional food quality and extended shelf-life.

Intelligent packaging

Intelligent packaging refers to the use of packaging as an intelligent messenger to monitor the condition and provide quality information of packed foods to the consumers (de Kruift et al., 2002). Indicators such as temperature, microbial growth, product authenticity, and pack integrity are used in intelligent packaging. At the moment, freshness (Figures 5 and 6) and leakage indicators are commercially available for monitoring food



Figure 4. Oxygen absorber in polyethylene tray packed meat (Packaging Europe, 2013).



Figure 5. Meat packed in polyethylene trays with fresh label monitors detecting expiration date through colour-changing as a response to the ammonia level emitted by aging food (Marlin, 2012).



Figure 6. Packaged golden drop fruit with food spoilage indicator label (Green = fresh; orange = warning) (Nopwinyuwong et al., 2010).

Table 2. Examples of the effects of packaging on quality and shelf-life of horticultural products.

Product	Packaging material	Effects on quality attributes	Reference
Plum	Cardboard box (compared to unpackaged).	Fruit firmness was retained 55-60% compared to 36-47% in unpackaged produce. High Chroma value (good colour) in packaged fruit compared to unpackaged fruit was recorded	Valero et al. (2004)
Blueberries	Poly lactide containers (compared to clamshell containers)	Poly lactide containers had 4% weight loss compared to 48% for clamshell containers after 9 days of storage at 10°C.	Almenar et al. (2008)
Pomegranate juice	Glass bottle (Compared to paperboard cartons with polyethylene layers)	High juice quality was obtained in glass bottle package. Anthocyanin degradation was 78% in juice packed inside glass bottle compared to 95% for paperboard cartons.	Pérez-Vicente et al. (2004)

quality. High temperatures are often correlated with food deterioration as result of irreversible biochemical reactions combined with microbial growth (de Kruift et al., 2002). The time-temperature indicator therefore measures the change that mimics the targeted quality attribute with the same behaviour under the same time-temperature exposure. The pH and enzymatic changes of the product might also give information about the quality of food. The Vitsab TTI indicator (Vitsab Sweden AB, Sweden) measures the enzymatic reactions that subsequently cause pH change of the product. The package contains the Vitsab TTI indicator window indicating the difference between acceptable and distasteful.

IMPACTS OF PACKAGING ON FOOD QUALITY, SHELF-LIFE AND SAFETY

Sensory and nutritional quality

The type of packaging exerts considerable effect on the sensory quality of produce. For instance, litchi (cv.

'Mauritius') packed in biorientated polypropylene (BOPP-3) were found to be of exceptional nutritional and sensory quality compared to fruit packed in BOPP-1 and BOPP-2 with less polypropylene layer (Sivakumar and Korsten, 2006). In addition, non-perforated polypropylene plastic bags were found to be more suitable for table grapes than perforated plastic bags based on higher sensory scores for crunchiness, juiciness and overall fruit quality.

Previous studies have demonstrated the potential of packaging to either negatively or positively influence the nutrient composition of food. Some packaging materials and forms promote nutrient loss during storage whilst some can preserve nutrients (Table 2). For instance, high

losses of aroma compounds have been reported in citrus juices packed in low density polyethylene paperboard than other packaging (Ebbesen et al., 1998). Mexis et al. (2009) studied the effects of different packaging materials and found considerable variability in product shelf life, with maintenance of nutrient content ranging from 2 to 12 months depending on type of package.

Shelf life

Packaging is often used as a tool to extend shelf life by preventing or reducing water loss, especially in fresh produce. Studies by Miller and Krochta (1997) showed that polyethylene bags reduced water loss and extended storability of various fruit and vegetables. Unpacked foods are often exposed to a range of microorganisms which have the potential to reduce shelf-life (Paine and Paine, 1992). The choice of packaging type and material has also effects shelf-life. For instance, Lee et al. (2002) reported that red pepper paste packed on polyethylene plastic had prolonged shelf-life compared to other forms of plastics, while Mexis et al. (2009) reported prolonged shelf-life and reduced microbial growth of shelled-walnuts packed on polyethylene terephthalate//polyethylene compared to polyethylene pouches.

Food safety

Harmful microorganisms feeding on unpacked food which are later consumed by humans can result in food poisoning, sickness or even death (Paine and Paine, 1992). Maintaining hygiene during food handling is important to assure the safety of consumers as well as promote longer shelf-life of food products. While effective

Table 3. Examples of the effects of packaging on horticultural food product losses and waste.

Product	Packaging	Effect on quality attributes	Reference
Sweet corn	Polystyrene trays wrapped (Polyolefin film) versus polystyrene trays (PVC film)	Decay of polyolefin film wrapped cobs was 1.5% compared to 45.2% decay for PCV film	Aharoni et al. (1996)
Sweet corn	Cardboard trays (Polyolefin film) versus Cardboard trays (PVC film)	Decay of polyolefin film wrapped cobs was 1.5% compared to 51.4% decay for PCV film	Aharoni et al. (1996)
Blueberries	Poly lactide containers versus clamshell containers	Berries packed on clamshell containers were unmarketable after 3 days of storage at 10°C unlike Poly lactide packed fruit that was still marketable after 18 days of storage	Almenar et al. (2008)
Cabbage	Monooriented polypropylene (OPP) trays versus PVC-PE trays	OPP trays prolonged shelf-life to 10 days unlike PVC-PE packed vegetable with 7 days shelf-life	Pirovani et al. (1997)
Celery	Perforated polypropylene (PP) film versus unpackaged	PP film allowed a shelf-life of 31 days while unpacked was unacceptable after 20 days	Rizzo and Muratore (2009)
Tomato	Plastic container versus cartons	Plastic container had 39.8% fruit loss while 80.6% was lost in carton stored fruit after 21 days storage at 10°C	Linke and Geyer (2002)
Red pepper	Polyethylene bags versus unpacked	Fruit packed in polyethylene bags had no decay, whereas fruit inside polyethylene bags had 11.7% decay after 14 days at 3°C	Meir et al. (1995)

packaging contributes to reducing spoilage and maintaining food quality, studies have also shown that packaging (and its related components) is a potential source of food contamination (Muncke, 2009). Some substances used in food packaging such as bisphenol have been found to contain endocrine disrupting compounds that are highly detrimental in biological systems (Vom Saal et al., 2007). Muncke (2009) described the contamination of food by packaging as being regulated by diffusion-controlled processes which depend on temperature and storage time of the product. This process leads to the leaching of food contaminants compounds from packaging to foodstuff.

ROLE OF PACKAGING IN REDUCING FOOD LOSSES AND WASTE

Roughly 30 to 40% of food produced in both developed

and developing countries are lost or wasted, with more losses occurring in developing countries (Godfray et al., 2010). The lack of proper postharvest technologies and cold-chain infrastructure are often cited as the principal factors aggravating food losses and waste in developing countries. The use of cost-effective and resource-efficient packaging technologies can contribute to reducing food losses and waste during postharvest handling (Opara, 2011). Almost one-third of rice grain produce in Asia may be lost due to pests and spoilage related to poor packaging equipment, and 10 to 15% postharvest losses of cereals and grain legumes are commonly recorded in developing countries (FAO, 1997). Some regions in Africa and Latin America experience postharvest food losses as high as 50%.

Several researchers (Table 3) have reported the potential of applying appropriate packaging to reduce postharvest losses and waste in a wide range of products

(Marsh and Bugusu 2007; Queded et al., 2011). For example, García et al. (1998) reported decay incidence of 86.5% in unpackaged strawberries compared to only 33.8% in fruit packaged with polypropylene film. Rizzo and Muratore (2009) prolonged the shelf-life of celery by 31 days using perforated polyethylene film while celery that was not packaged decayed before 20 days of storage. In another study demonstrating the importance of packaging in relation to food waste, Meir et al. (1995) reported 11% decay incidence of unpackaged red pepper stored at 3°C for 14 days compared with no decay in packaged produce. As shown in Table 3, selecting appropriate packaging material is a critical factor in realising the potential of packaging to reduce postharvest food losses and waste.

THE IMPACT OF PACKAGING ON FOOD PRICE

While packaging contributes to reducing postharvest food losses and waste and maintaining product quality and safety, it also affects the cost of the product to the consumer. On the other hand, like other energy intensive industries, the price of packaging material is also affected by energy costs which are often linked to crude oil price. Generally, the cost of packaging material represents 17% of the total cost of product (Lange and Wyser, 2003). The type of packaging used also influences the price of food products. Products packed in glass bottles generally cost higher than those on plastic bottles (Lange and Wyser, 2003) and this is commonly attributed to higher transportation costs associated with higher weight of glass packages. Packaging exerts influence on food prices in developed countries than in developing countries, with packaging and marketing accounting for a greater proportion of food prices in developed than developing countries (Elobeid and Hart, 2007). Consumer willingness to pay high prices for products is closely related to packaging style and material used.

FUTURE PROSPECTS AND CONCLUSIONS

Packaging is an essential component of the food system and plays a critical role in containing, protecting and preserving food and other agro-industrial raw materials from field to the end user. Researchers have shown that the use of appropriate packaging can contribute to reducing food losses and waste, and maintenance of product quality and safety. However, packaging is a major contributor to the cost of food, and packaging waste has been implicated as a major cause of municipal waste stream. The issue of food contaminants associated with packaging particularly due to use of recyclable paper needs to be addressed. To address these safety and sustainability challenges, the role of cost-effective and resource-efficient packaging design is crucial. The

application of emerging technologies in packaging design offers new prospects for advanced quality monitoring using electronic devices that monitor and report real time information on nutritional quality and safety of food.

The synergy of recent advances in biotechnology, nanotechnology and material science offer new opportunity to develop new packaging materials and design to address some of the changes facing the industry, including product safety, environmental impacts and sustainability of packaging. With increasing power and lower cost of information and communication technologies, the development of highly advanced packages incorporating nano-sensors to capture and analyse environmental signals and adjust stress response treatments on fresh foods through series of controllers to maintain storage quality and subsequently prevent food spoilage have become more of a reality than science fiction. Recent developments and applications of nanotechnology have produced antimicrobial packaging in response to the problem of food spoilage and losses. For fresh horticultural produce which continue to be alive after harvest, balancing the cold chain requirements through optimal ventilation design without compromising the mechanical integrity of the package will remain a packaging design challenge for engineers and food scientists.

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