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Active and Intelligent Packaging with Phase Change Materials to Promote the Shelf Life Extension of Food Products

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Abstract

Active packaging aims to extend the shelf life of fruits and vegetables using active agents such as Oxygen, Carbon-di-oxide, ethylene scavengers and moisture absorber. Intelligent packaging provides information about the fruits quality inside the package to the customer and this packaging technology detects the internal changes of fruits and vegetables using sensors and indicators. Further to improve the post-harvest storage PCM such as Rubitherm can be used depending on the package box dimension to remove the field heat from the products and maintain its temperature with low variation during transport and display. Gel packs having less weight with PET and PS can also be an alternate method in the packaging. The application of these technologies may lead to a revolution in post-harvest storage, transportation, and further retail sale. This paper reviews the theoretical principles of food packaging and recent developments in packaging technologies using PCMs.

Keywords: Active packaging, Intelligent packaging, Phase change materials, Shelf life extension, Fruits

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1. Introduction

The Food and Agricultural Organization of the United Nations (FAO) shows about 33% of the sustenance delivered on the planet. For human utilization, it was wasted each year about 1.3 billion tons. It's worth almost USD 680 billion in industrialized nations and USD 310 billion in developing nations [1]. The world's population is predicted to rise from 7 to 8.5 billion by 2030, and to 9.7 billion by 2050. The population will grow totally in developing countries, especially in Africa. In Europe and western countries, population statistics will rise gradually or even drop. Population groups >60 years are projected to grow faster. People over 80 will reasoning for around 10% of the world's population in 2050. In 2008, 50% of the world's population lived in cities. In 2030, about 60% of the global population will live in cities. A smaller amount of developed countries, about 3.9 billion people will then settle in urban areas. Although cities cover only 2% of the Earth's surface, they harvest 80% of global economic output, 70% of global greenhouse gas emissions, and consume 75% of the global energy [2].

Food waste at the end of the supply chain is also considered in all regions, with 15–30% to be rejected on the basis of weight by clients. In developing regions, losses in agricultural production lead to total losses throughout the supply chain. The accessibility, openness, and usability of natural resources are fundamentals for growing economies as well as the agricultural sector. High-quality land availability of water and nutrients are roots for food and renewable energy production. Yet, the quality of land suitable for agriculture is gradually endangered by degradation due to over-exploitation, pollution, the impact of climate change, competition for land and shortage of water. Water demand is predicted to increase by 55% between 2000 and 2050.The issue of food wastes is of high consequence in the activities to battle hunger and improve food security on the planet's least privileged nations [3]. Figure 1 shows the worldwide measurable food losses and waste per year.

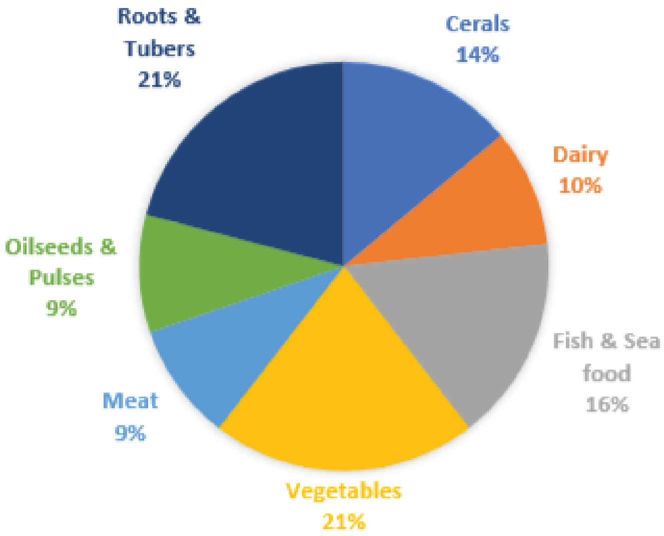

Figure 1: Different types of food loss in terms of percentage [1].

In order to prevent food waste and promote the fruits shelf life, package boxes containing PCMs are used while transporting fruits from producer to consumer. The objective of this review paper is to understand the melting process of phase change materials (PCMs) in a package box at different ambient temperatures. The numerical results using several paraffins as Rubitherm RT8HC, RT5, RT11HC and RT5HC were obtained.

2. Packaging Material

Nowadays, the packaging is recognized as a fundamental component to address the key test of supportable food utilization and is picking up enthusiasm among researchers. The packaging is a central element in the preservation of food quality, primarily by controlling the exchange of natural gas and vapor with the outside atmosphere, ensuring that food quality is preserved during storage, preventing problems of food safety (prevention of foodborne diseases and contamination with chemicals) and extending the shelf life of food. Important advantages of reducing food waste due to extended shelf-life are expected. Food packaging materials have a complete life cycle. Packaging materials regularly utilized for food packaging are glass, metal, paper and cardboard, wood, and plastic, just as packaging material from blended substances as for crude materials utilized for their generation. All the previously mentioned materials have points of interest and weaknesses [4]. A mathematical simulation based on the modeling of heat and mass transfer reactions to food packaging systems is a promising tool to answer adequate design and adaptation of food packaging to food demands. The innovative study has concentrated on creating bioplastics from organic waste flows (plant residue and agricultural products, waste disposal seed, etc.) which seeks to fit into a belief that is not competing with food use, and fully biodegradable to react to the excesses. In addition, it was supported in the European Commission by a European Circular Economy Package, EU waste law [5]. A step to promote a circular economy and health being of next-generation the food packaging industry must use new packaging solutions and choose the best packaging solution, in a fair and transparent manner, that contributes to the overall reduction of food losses and persistent plastic accumulation [5].

3. Phase Change Material

Phase Change Materials (PCMs) can be used in transport, storage, and display stages to keep up the cold chain of frozen food, drinks, pharmaceutical goods, textile industry, blood subsidiaries, electronic circuits, cooked food, biomedical products, fruits, and vegetables. Materials to be applied for phase change thermal energy storage must have a large latent heat and high thermal conductivity. They must have a melting temperature lying in the scope of activity, melt constantly with the least subcooling and be synthetically steady, costless, non-toxic, and non-destructive. Energy storage assumes imperative roles in saving accessible energy and improving its application since numerous energy sources are irregular in nature [6]. The Suitable phase change temperature had better be picked in the temperature scope of 4 °C to 8 °C. For some applications, the PCM is liquid at room temperature, so its handling can become a problem. To limit its leakage while transforming from the solid to liquid phase, the PCM must be contained in some protective thin layer film. The suitable use of biomassderived materials and biodegradable polymers for encapsulating components with related environmental advantages. Various biopolymers were tested and, finally, polycaprolactone (PCL) was selected as the most suitable shell material, as this material was capable of encapsulating the largest amounts of PCM [7]. PCM is a material chosen for its high inactive warmness storing material. The phase change can happen in different structures: solid to liquid, solid to gas, and liquid to gas. However, Solid to liquid type of PCMs is the most used since they have profited by numerous advancements during the previous two decades [8, 9]. Chalco-Sandoval et al. [10] have developed multi-layer heat storage structures based on Polystyrene for use in food cooling. The nature of encapsulated material might affect the structure of multilayers, storage time, and Ambient temperature. The potential use of these materials in food packaging applications for efficient temperature buffering was accessed. Apart from its melting and faster nucleation, paraffin has several favorable attributes, for example, it can undergo very long freezing and melting cycles.

Figure 2: Phase change material – Gel Packs [25].

Paraffins, however, also have some unwanted properties such as low thermal conductivity, plastic container incompatibility, and high flammability. Researchers worldwide are exploring the utilization of PCMs to answer temperature uncertainties [11].

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PCM Calculations This section provides an example to determine the weight of the PCMs required to maintain a food product at the desire conservation temperature during a specific time. The thermal resistance, R, is given by Equation 1 [12].

$$R = \frac{A \cdot \Delta T}{\dot{m} \cdot L_f} \tag{1}$$

Where,

A - Surface Area of the box [m^2]

ΔT - Temperature Difference (between the ambient air the melting point of PCM) [°C]

$\dot{m}$ - Melt rate [kg/h]

R – Thermal resistance (values in Table 1) [m^2 °C /W]

L_f - Latent heat (technical data sheet of Rubitherm) [kJ/kg]

To maintain the peach fruits at 8 °C for 8 hours in ambient with a temperature of 20 °C using corrugated closed box lined with 19-mm-thick Expanded Polystyrene (EPS) panels, Equation 2 is used to obtain the weight of PCM that is required.

$$\dot{m} = \frac{A \cdot \Delta T}{R \cdot L_f} \tag{2}$$

$$\dot{m} = \frac{0.485.\ 12}{1.66.\ 190} = 66.4\ g/h = 531.3\ g/8h$$

Thus, 531.3 g of RT8HC PCM is required to maintain the peach fruits at 0 °C for 8 hours.

Table 1: PCM materials Thermophysical characteristics [12].

PCM Materials	Melting Point (°C)	Latent heat (kj/kg)	R values (m^2 °C/W)	Surface area (m^2)	Insulating material used
RT8HC	8	190	1.66	0.485	C-Flute corrugated fibreboard * box with 19 mm thick EPS foam panels
RT18HC	18	260	1.63	0.485	C-Flute corrugated fibreboard* box with 13- mm-thick EPS foam panels
RT5HC	12	200	1.05	0.485	C-Flute corrugated fibreboard box, 4 mm thick
RT11HC	6	180	1.25	0.486	Oyster ThermalCorl®+ box
RT5	5	180	1.41	0.487	ThermalCor® box with ThermalCor® tube

Figure 3 shows the calculated values of the melting rate for 8 hours to require the amount of PCM material to maintain the fruits under a modified temperature environment and also calculated different ambient temperatures of 0, 5, 10, 15, 20 and 25 °C for the comparison of PCMs required in different phase transition conditions. Previously, researchers suggested using the Gel packs shown in Figure 2 with Polyethylene terephthalate (PET) and Polystyrene (PS) material. This solution provides a low weight and easy to handle for fruits and vegetable packaging without affecting nutrients value.

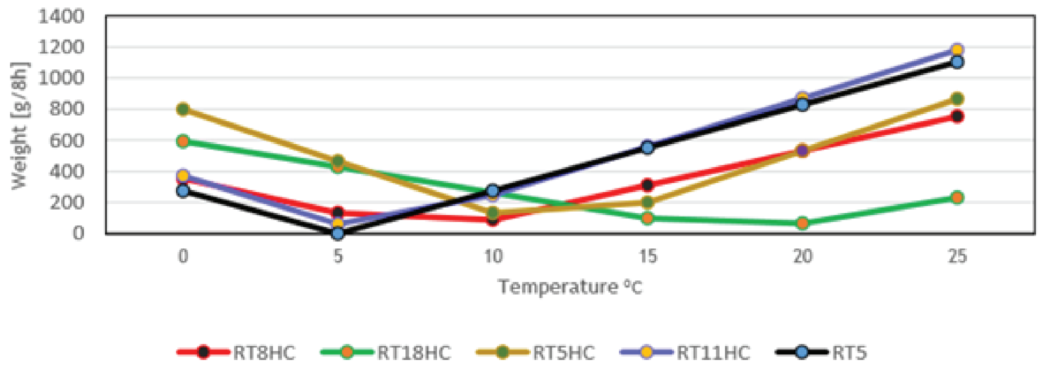

Figure 3: Melting rate of PCMs for 8 hours

4. Active Packaging Active

Packaging of food is a case of a development that goes past the conventional elements of the package in which the package and its condition connect to broaden the lifespan of realistic usability of food or to improve its security or tangible properties while keeping up the nature of food [13]. Nanotechnology suggests food safety in terms of packaging for confirming an extended shelf life by avoiding decay or loss of food nutrients. Active packaging has a desirable role in food preservation other than providing an inert barrier to external conditions [14]. Chitosan is a cationic polysaccharide from chitin, and it is pH responsive. The film-framing, antimicrobial and biocompatible highlights of Chitosan make it a great for active food packaging [15]. A large portion of plants, particularly edible oils plants, are known for their potential advantages to human comfort as a result of their natural benefits, for example, anti-cancer, anti-inflammatory, anti-diabetic, anti-ulcerogenic, antidepressant, anti-anxiety, including cancer prevention agent and antimicrobial properties and as a result of their organoleptic properties [16].

An active packaging system should be considered an innovative way in the field of food packaging. They interact with the packed product, change the condition of the packed food, and control its quality at the same time. Active packaging represents a large and diverse group in terms of both its purpose and solution applied. The use of proper active packaging extends the shelf life of products through its impact on processes emerging in food. Active packaging may use, not only, but also in the following conditions:

- Physiological processes, e.g. breathing of fresh fruits and vegetables.
- Chemical processes, e.g. oxidation of fats.
- Physical processes in the case of bread staling.
- Microbiological changes due to the impact of microorganisms.
- Infections caused by insects.

4.1. Active Agents

Active packaging includes technologies used to extend the food shelf-life. This consists of incorporating active agents into packaging that interact with food through different mechanisms such as eliminating unwanted compounds or adding beneficial compounds to the product [17, 18]. A few investigations have exhibited the potential advantage of utilizing fundamental oils as dynamic specialists in packaging materials, keeping up the underlying qualities of the food, securing it against microbial decay and thus extending its shelf life [18, 19]. Previous studies have shown some specific fruit susceptibility to chilling injury, so low temperatures such as 2 °C to 8 °C are not effective in extending shelf life. Some chilling disorders and fruit senescence, however, could be prevented or delayed by storing fruit at 0 °C [18, 20, 21].

5. Intelligent Packaging

Intelligent packaging systems monitor the condition of packaged foods to give information about their quality during transport and storage. Intelligent packaging can be defined as “a control system inside packaging which is able to perform intelligent functions such as standby, detection, tracking, recording, and communicating in order to provide individual links in the packaging chain, i.e. producers, distributors, and sales representatives and consumers, with certain parameters” [22].

The expression ”intelligent” includes an ”ON/OFF” exchanging capacity on the package because of evolving outer/inner boosts, to convey the item’s status to its buyers or end clients [23]. The package data not just about the product itself (origin, validity date, organization), but additionally have the capacity to advise about the historical backdrop of the product (storing conditions, headspace synthesis, microbial development, and so on). Thus, intelligent packaging speaks to a major advance forward to safe from food spoilage and to improve food logistics and discernibility [13]. It is broadly acknowledged that three principle advancements can acknowledge intelligent packaging frameworks:

- Indicators, which plan to give more comfort or potentially to educate shoppers about the food product quality;
- Logistics information, for example, standardized tags furthermore, radiofrequency identification tags (RFID), which are explicitly expected for capacity, circulation, and discernibility purposes; and
- Sensors, which consider a quick and unmistakable measurement of the environment or about the analytes in foods [23, 24].

6. Conclusions

In the field of post-harvest handling of fresh horticultural products, active packaging and intelligent packaging is an emerging area not only for product preservation but also for the safe transport of food products. Active packaging protects fruits and vegetables against external and other foreign infections using some active agents such as edible oil and controlled packaging makes the package feasible for a particular period. Intelligent packaging provides information about the fruits inside the package to the customer and this packaging technology detects the internal changes of fruits and vegetables using sensors, indicators, etc. The application of these technologies may lead to a revolution in post-harvest storage, transportation, and further marketing handling.

Based on the numerical results, Rubitherm RT8HC and RT5HC requires less amount of PCMs to maintain the fruits at an ambient temperature of 10 °C for 8 hours. RT5, RT11HC, and RT8HC are required very less amount of PCMs to maintain the fruits at an ambient temperature of 5 °C for 8 hours, using corrugated closed box lined with 19-mm-thick EPS panels. The future work aims to develop an experimental test on different types of biomaterial boxes in cold chambers to predict their Mechanical and thermal behavior. The experimental results are analyzed to promote shelf life of food products in eco-friendly package boxes.

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