Integrative Mathematical Modelling for Packaging Design of Fresh Produce

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Abstract

Modified Atmosphere Packaging (MAP) of fresh produce is a dynamic system and relies on the modification of the atmosphere inside the package, achieved by the natural interplay between two processes, the respiration of the product and the transfer of gases through the packaging film, which leads to an atmosphere richer in CO_2 and poorer in O_2. A real challenge is how to integrate the mathematical modelling depicting product respiration rate and package permeability on a packaging system. The "pack-and-pray" approach and in-house trial-and-error experiments are normally used to find a suitable packaging material, film area for gas/water vapour exchange, package size and the quantity of product to be packaged. This is both time and labour intensive and a potential risk to health. Pack-in-MAP® web-based software was developed combining various mathematical models on product respiration rate and package permeability in order to determine the needs for packaging of fresh produce and predict the in-package gas composition during storage period, the effect of temperature of supply chain, and the effect of product/package variability on the package gas composition providing a system which allows selection of suitable packaging materials for fresh produce Software could be used to test several solutions on a value-for-money basis in order to achieve results while minimising costs and avoiding costly trial-and-error approaches.

Keywords: Fresh produce, MAP, respiration, permeability, packaging simulation, Pack-in-MAP®

Introduction

The segment of ready-to-eat fresh-cut consumer products is one of the few that has shown consistent growth in the last few years. Trends for healthier eating push increased consumption of fruits and vegetables (Lange, 2000), while trends for convenience stimulate ready-to-eat products. However, fresh produce are living commodities which respire even after harvest. Modified atmosphere packaging (MAP) is a well known technique for preserving fruit and vegetables for longer time. It relies on the modification of the atmosphere inside the package, achieved by the natural interplay between two processes, the respiration of the product and the transfer of gases through the packaging film, which leads to an atmosphere richer in CO_2 and poorer in O_2. Low O_2 & high CO_2 are widely assumed to maintain quality & extend shelf life of fresh produce (Fig. 1)

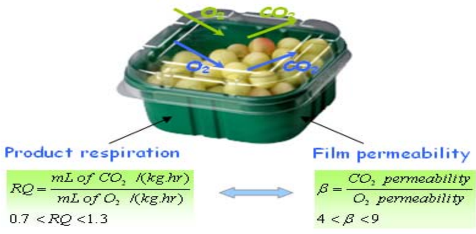

Figure 1. Principles of MAP

The major challenge faced by the fresh produce industry is "What packaging material do I use?" While it may be possible to find an appropriate packaging material through simply testing various packages (Pack & Pray approach), the optimal packages is likely to be found by taking an integrative mathematical modelling process. There is a wealth of published information on MAP, which could be compiled to find which polymeric films would be most suitable for a particular produce under a given set of processing and environmental conditions. Such analysis could provide an initial screening of films, point out their potential limitations and allow testing very few packages because you will have already determined what will not work for you.

The ultimate aim of this integrative mathematical modelling process is to contribute to the development of a knowledge-based system, to design an optimal package by selecting a suitable film for a given product, its area and thickness, filling weight, equilibrium time, and the equilibrium gas composition at constant and varying temperature conditions and simulate several solutions on a value-for-money basis while minimising costs and avoiding costly trial-and-error approaches.

Materials and Methods

MAP design entails consolidated knowledge of the i) fresh produce quantification, ii) polymer engineering and iii) converting technology, and a successful packaging needs the interaction of these three different disciplines (Brandenburg and Zagory, 2009). MAP design for fresh produce requires an integrated model considering a). Product respiration rate as a function of both gas composition and temperature, b). Amount of product, c). Permeability of packaging to O_2, CO_2, as a function of temperature and d). Packaging geometry and size, among other product characteristics as shown in Fig. 2 (Mahajan *et al.*, 2006, 2009).

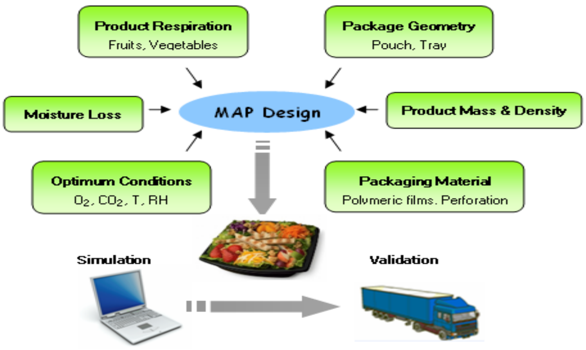

Figure 2. Factors affecting MAP design

A real challenge is how to integrate the needs of product to find an optimal package. The answer is either to go for a trial-and-error experiments or an engineering approach where mathematical equations depicting product respiration rate (Eq. 1) and package permeability (Eq. 2) could be used to solve the mass balance equations of a packaging system **(**Mahajan *et al.*, 2007**)**.

$$P_{O_2} = \left[P^*_{O_2} e^{\left[\frac{-E_{O_2}}{RT}\right]} + \frac{\pi \; R_H^2 \times D_{O2}}{(e + R_H)} \times N_H \right] \quad (1)$$

$$R_{O2} = \frac{\alpha \times y_{O2}}{\phi + y_{O2} \times \left(1 + \frac{y_{CO2}}{\gamma}\right)} \times e^{\left[\frac{-E_a}{RT}\right]} \quad (2)$$

Results and Discussion

Considering all the above factors, the differential equations of mass balance for O_2 and CO_2 in MAP containing a respiring product in a permeable package can be generated (Fig. 3).

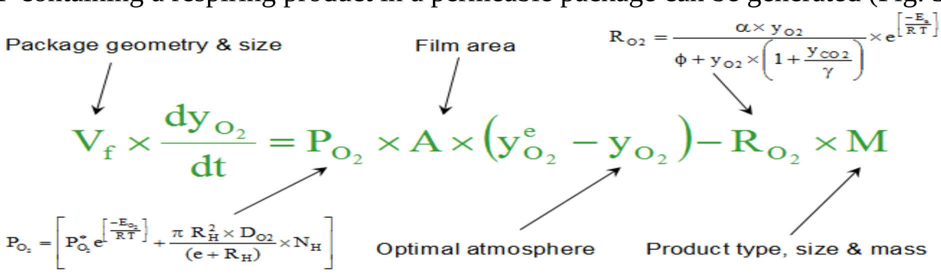

Figure 3. Integrative mathematical modelling of MAP for packaging design of fresh produce

Ultimate result of the integrative mathematical modelling was a web-based (www.packinmap.com) packaging design software called Pack-In-MAP® (Mahajan *et al.*, 2009). Pack-in-MAP® is a web-based software developed by University College Cork, Ireland, that helps in designing modified atmosphere packages for fresh and fresh-cut fruits and vegetables. The software determines the needs for packaging of fruits and vegetables in order to generate their optimal gas composition for maintaining quality and maximize food shelf-life (Mahajan *et al.*, 2009). Pack-in-MAP® contains databases on product characteristics, respiration rate, optimum temperature, and optimum range of O_2 and CO_2 concentrations as well as permeability of different packaging materials, including micro-perforated films. Pack-in-MAP® software can be accessed online, the user defines the type of product, storage conditions, amount of product to be packed, and size and geometry of the package. The software selects the optimum gas composition (O_2 and CO_2) and calculates the respiration rate for that product. The software then selects the best possible films in the given range of permeability ratio (Fig. 4).

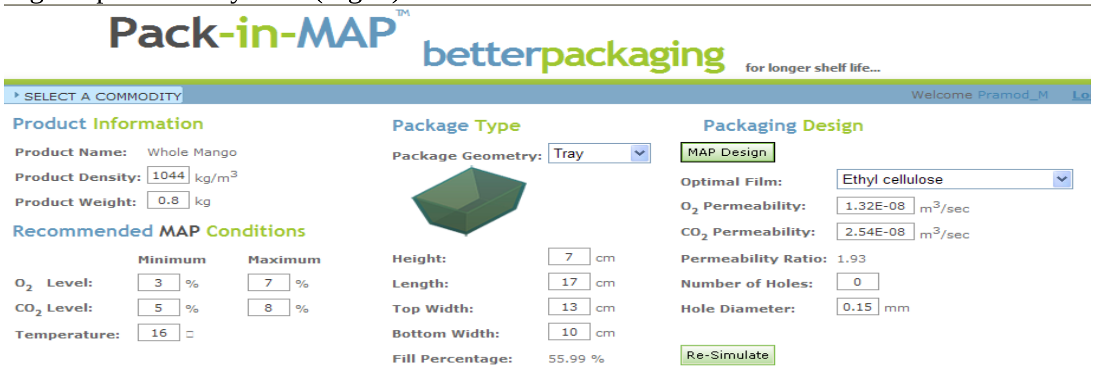

Figure 4. User interface of Pack-in-MAP® software showing the input parameters (i.e., product information, package geometry (e.g., tray) and dimensions), the recommended MAP conditions and temperature (e.g., 16ºC) and the output parameters (recommended film, film permeability to O_2 and CO_2 and if necessary number of holes and its diameter.

Pack-in-MAP® software then simulates how the package O_2 and CO_2 changes over storage time for the given time-temperature profile for the particular product, indicating the O_2 and CO_2 at equilibrium and the time required to reach it (Figure 5a). It also has the capability of simulating the impact of product/package variability on package atmosphere (Figure 5b).

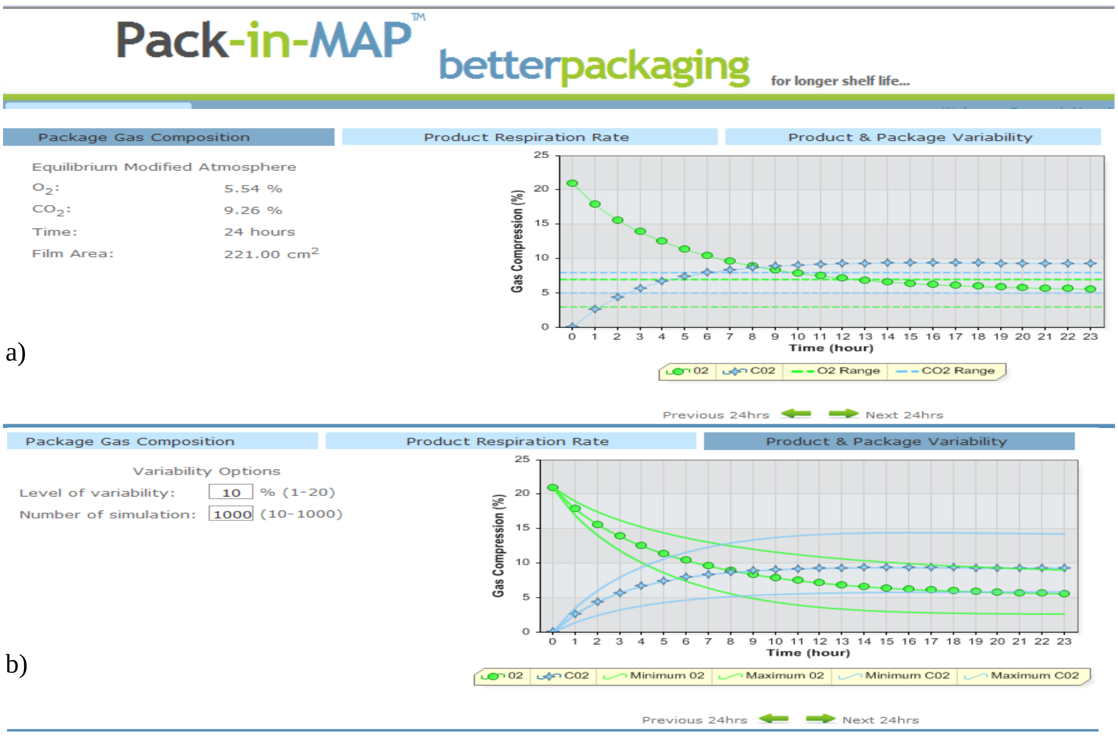

Figure 5. Pack-in-MAP® software showing the kinetics of gas exchange in the MAP package (a) and the impact of product & package variability (e.g., 10%) on internal package atmosphere for mango MAP design under the set conditions.

The software has been successfully used to design MAP of several fresh-, fresh-cut and mixed products (e.g., mushrooms, carrots, cheese, mango and onions) and the results have been validated with the experimental data.

Pack-in-MAP® software enables the users to:

- Choose the best packaging material or calculate oxygen transmission rate (OTR) to achieve equilibrium modified atmosphere (EMA) rapidly and within the optimal range,
- Estimate the size and number of micro-perforations in the film,
- Simulate the package O_2 and CO_2 over time without any knowledge of mathematical models, package design and MAP itself,
- Study the impact of product/package variability on package atmosphere
- Design a package considering changes in storage temperature during real life distribution chain
- Input customized data to tailor design packaging according to customers own requirements.

Conclusions

Integrative mathematical model for packaging design of fresh produce have been developed, validated and added to the Pack-in-MAP® software knowledge-based system, with the overall goal to design optimal packages, avoiding costly trial-and-error approaches with the added benefit of testing several solutions on a value-for-money basis. Potential users will be able to define a packaging solution to improve shelf life and prevent potential safety hazards.

Acknowledgments

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