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Development of user-friendly software for design of modified atmosphere packaging for fresh and fresh-cut produce

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Abstract

There is a wealth of published information on modified atmosphere packaging (MAP) but a lack of systematic treatment of the data in order to develop knowledge management systems that can provide information to users on which films to use for particular purposes and targets. This paper reports the development of user-friendly software for MAP design of fresh and fresh-cut produce. The software can select suitable packaging materials and define the amount of product to be packed or the area of the film that should be available for gas exchange. Two databases have been built in the software, which include recommended gas composition for 38 products, 75 respiration rate models, and permeability data for 27 polymeric films. This software was successfully tested for some products and an example for mango and Galega kale is described.

Keywords: Fruits; MAP; Packaging films; Permeability; Respiration rate; Vegetables

Industrial relevance: The PACKinMAP software selects the best possible film type for the given type of fresh or fresh cut fruit/vegetable. A manufacturer can type in a specific food product, such as a golden delicious apple, and the software will tell him the ideal type of packaging material according to the supplier or the retailer's needs. The software has also been found to simulate the package for any type of real-life distribution temperature history thus testing the ability of the package to withstand abuse.

1. Introduction

Modified atmosphere packaging (MAP) of fresh produce relies on 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, that leads to an atmosphere richer in CO_2 and poorer in O_2. This atmosphere can potentially reduce respiration rate, ethylene sensitivity and production, decay and physiological changes, namely, oxidation (Kader, Zagory, & Kerbel, 1989; Saltveit, 1993).

The objective of MAP design is to define conditions that will create the atmosphere best suited for the extended storage of a given produce while minimising the time required to achieve this atmosphere. This can be done by matching the film permeation rate for O_2 and CO_2 with the respiration rate of the packaged produce. As different products vary in their behaviour and as MA-packages will be exposed to a dynamic environment, each package has to be optimised for specific demands (Chau & Talasila, 1994; Jacxsens, Devlieghere, Rudder, & Debevere, 2000; Saltveit, 1993). A MAP system not properly designed may be ineffective or even shorten the storage life of a product: if the desired atmosphere is not established rapidly the package has no benefit; if O_2 and/or CO_2 levels are not within the recommended range, the product may experience serious alterations and its storage life is shortened.

Exama, Arul, Lencki, Lee, and Toupin (1993) calculated the required O_2 and CO_2 permeability for various fruits and vegetables to create optimal gas concentrations in the MA packages. These calculations were based on the steady state respiration rate whereas in MA package the respiration rate changes as the atmosphere is modified. Hence, the design should take into consideration not only steady-state conditions

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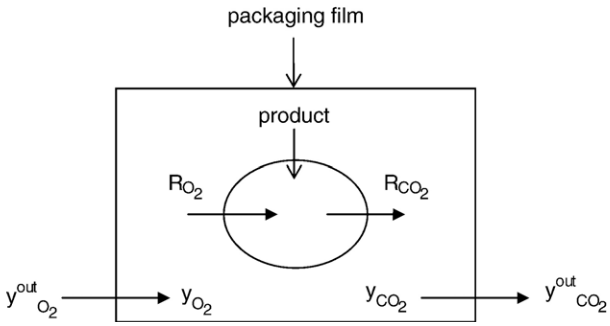

Fig. 1. Gas exchange in a modified atmosphere package containing fresh produce.

(product respiration rate and film permeability), but also the dynamic process, because if the product is exposed for a long time to unsuitable gas composition before reaching the adequate atmosphere, the package may have no benefit. Storage temperature is never constant in the distribution chain of fresh produce. Due to the temperature dependence of the respiration rate and of the gas permeability of a packaging film, fluctuating temperatures result in changes of the internal O_2 and CO_2 concentrations (Jacxsens et al., 2000). Because of the difference in the rates of change of permeability and respiration rate with temperature, a film that produces a favourable atmosphere at the optimal storage temperature may cause excessive accumulation of CO_2 and/or depletion of O_2 at higher temperatures, a situation that could lead to metabolic disorders (Beaudry, Cameron, Shirazi, & Dostal-Lange, 1992; Cameron, Beaudry, Banks, & Yelanich, 1994; Cameron, Patterson, Talasila, & Joles, 1993; Exama et al., 1993; Joles, Came0ron, Shirazi, Petracek, & Beaudry, 1994). A package poorly designed may actually reduce the product shelf life and even induce anaerobiosis, with the possible growth of pathogens and concomitant effects on product safety.

There is a wealth of published information on MAP, yet no systematic theoretical study has been conducted to establish which commercially available plastic films would be most suitable for MAP of a particular produce (Exama et al., 1993). Such analysis could provide an initial screening of polymeric films, point out potential limitations, and help minimise the number of experimental trials. Simulation of a MAP system is the most appropriate method to allow a correct MAP design and consequently obtain a successful commercial product. The "pack and pray" procedure may have economic and safety hazard consequences and the "trial and error" approach is an extremely time consuming procedure. The objective of the work reported in this paper was to develop and test user-friendly software, called PACKinMAP, for designing MAP for fresh and fresh-cut respiring products.

2. Design methodology

MAP design requires the determination of intrinsic properties of the produce, i.e. respiration rate, optimum O_2 and CO_2 gas concentrations, and film permeability characteristics. The ultimate aim of this design process is to select suitable films for a given product, its area and thickness, filling weight, equilibrium time, and the equilibrium gas composition at isothermal and non-isothermal conditions.

When several films can be used to provide a protective atmosphere, their cost will be a major selection factor. It is also possible to envisage a situation where a cheaper film providing lower protection may be preferable, if the shelf-life extension is already sufficient for the purpose in question. The maximum possible protection regardless of cost can be a target, but some type of balance or of compromise may also need to be evaluated if the best solution appears excessively onerous.

2.1. Design equations

Fig. 1 schematically shows respiring produce stored in a package comprised of a plastic film. The simplest concept is to let the plastic film serve as the regulator of O_2 flow into the package and the flow of CO_2 out. Assuming that there is no gas stratification inside the package and that the total pressure is constant, the differential mass balance equations that describe O_2 and CO_2 concentration changes in a package containing a respiring product are:

$$V_f \frac{d(y_{O_2})}{dt} = \frac{P_{O_2}}{e} A\left(y^{out}_{O_2} - y_{O_2}\right) - R_{O_2} M \qquad (1)$$

$$V_f \frac{d(y_{CO_2})}{dt} = \frac{P_{CO_2}}{e} A\left(y^{out}_{CO_2} - y_{CO_2}\right) + R_{CO_2} M \qquad (2)$$

where V_f is the headspace (free volume) in the package, y is the gas concentration (in molar fraction), e is the thickness of polymeric film, P is the permeability of the package expressed in volume of gas exchanged per unit time and area and R is the respiration rate expressed in volume of gas generated/consumed per unit time and weight of the product (M); the subscripts O_2 and CO_2 refer to oxygen and carbon dioxide, respectively.

The software considers three different types of system: (i) polymeric films without perforations or microperforated; (ii) macroperforated polymeric films and (iii) perforation-mediated packaging systems. Non-perforated polymeric films yield low O_2 and low CO_2 concentrations because the CO_2 permeability of these materials is generally 3 to 6 times that of O_2 permeability (Exama et al., 1993; Yam & Lee, 1995). These materials are suitable for less CO_2 tolerant commodities such as mango, banana, grapes and apples. Perforated films have higher permeability rate but the ratio of CO_2 to O_2 permeability is much lower, approaching unity. Such films are, therefore, of great interest for commodities tolerating simultaneously low O_2 and high CO_2 levels such as fresh-cut products, strawberry and mushroom (Fishman & Rodov Ben-Yehoshua, 1996; Fonseca, Oliveira, Lino, Brecht, & Chau, 2000). Perforation-mediated packaging is a system where tubes, which may be packed with an inert filling, are inserted in an otherwise airtight package (Fonseca et al., 2000). This system is also adequate for products requiring high CO_2/low O_2 concentrations and minimises water accumulation inside the package; because the package is rigid, it is suitable for bulk products and for products sensitive to mechanical damage.