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A Decision Support System to design modified atmosphere packaging for fresh produce based on a bipolar flexible querying approach

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ABSTRACT

To design new packaging for fresh food, stakeholders of the food chain express their needs and requirements, according to some goals and objectives. These requirements can be gathered into two groups: (i) fresh food related characteristics and (ii) packaging intrinsic characteristics. Modified Atmosphere Packaging (MAP) is an efficient way to delay senescence and spoilage and thus to extend the very short shelf life of respiring products such as fresh fruits and vegetables. Consequently, packaging O_2/CO_2 permeabilities must fit the requirements of fresh fruits and vegetable as predicted by virtual MAP simulating tools. Beyond gas permeabilities, the choice of a packaging material for fresh produce includes numerous other factors such as the cost, availability, potential contaminants of raw materials, process ability, and waste management constraints. For instance, the user may have the following multi-criteria query for his/her product asking for a packaging with optimal gas permeabilities that guarantee product quality and optionally a transparent packaging material made from renewable resources with a cost for raw material less than 3 €/kg. To help stakeholders taking a rational decision based on the expressed needs, a new multi-criteria Decision Support System (DSS) for designing biodegradable packaging for fresh produce has been built. In this paper we present the functional specification, the software architecture and the implementation of the developed tool. This tool includes (i) a MAP simulation module combining mass transfer models and respiration of the food, (ii) a multi-criteria flexible querying module which handles imprecise, uncertain and missing data stored in the database. We detail its operational functioning through a real life case study to determine the most satisfactory materials for apricots packaging.

1. Introduction

Despite targeted campaigns and programs for promoting their health benefits, consumption of fresh fruits and vegetable is still limited by their short shelf life, which is not easily compatible with current modes of distribution and purchase (once a week) in medium- to high-income countries.

Beyond respect of the chill chain and initial food quality, Modified Atmosphere Packaging (MAP) was proved to be an efficient way to delay senescence and spoilage, without using controversial preservative compounds, and so to extend shelf life of fresh produce (Floros and Matsos, 2005; Guillaume et al., 2008; Zagory and Kader, 1988). MAP relies on the establishment of an optimal/recommended atmosphere for the produce and can be achieved by matching the gas (O_2 and CO_2) permeation rate of the film with the respiration rate of the produce. If a wealth of information has been published on MAP (more than 400 occurrences for "modified atmosphere packaging and fruit and vegetable" in ISI Web of Knowledge), there is a lack of systematic treatment of the data using knowledge management system in order to provide a full (complete) Decision Support System (DSS).

By providing suitable information, such numerical tools could help designers and users to select film properties that best fit particular purposes and targets. This approach is especially important when developing packaging made from biodegradable materials, which becomes a new trend, as their limited barrier properties,

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possibly optimized using smart and/or composite multilayer material (Guillaume et al., 2010), can turn out to be an asset to extend shelf life of respiring foods (Cagnon et al., 2012; Guilbert et al., 2011; Guillaume et al., 2008). To facilitate MAP design, mathematical models, so-called virtual MAP, have been developed by researchers working in this field to design passive (Mahajan et al., 2007; Souza-Gallagher and Mahajan, 2013) or active MAP (Cagnon et al., 2012; Charles et al., 2003, 2005) for fresh and fresh-cut fruits and vegetable. Online applications are today available for free (www.tailorpack.com) or charged access (www.packinmap.com). Such numerical tools simplify the package design steps by predicting the gas permeability values that permit to reach recommended atmosphere for the target product and therefore to extend shelf life while maintaining quality and safety of the packed food.

Up to now, all the aforementioned tools only considered the gas permeabilities of the packaging material as a basis for packaging design. The design of food packaging is not only driven by maximizing shelf life of the food, and numerous other requirements may interplay for final decision, related to processing, marketing, commercial, or distribution concerns (as cost, process ability of constituents, industrial feasibility, environmental impact, safety and stability of the packaging material all over the food life cycle, waste management, etc.). Then, aside the constraint of food shelf life and quality, correlated to gas permeation rates of the material, it also relies on user's preferences, naturally expressed as wishes (e.g. transparent material would be preferred) or constraints (e.g. cost of raw material must be less than 3 €/kg). Some constraints and/or wishes are also related to the fact that consumers may reject the use of some additives or of nano-technology in the packaging material because of the unknown consequences on their health, or more simply they may prefer transparent rather than opaque packaging. To help stakeholders of the food chain in the choice of a packaging material that would suit all the requirements of a given fresh fruit or vegetable, development of decision aid tools is foreseen.

The European project EcoBioCap (www.ecobiocap.eu) aims at designing the next generation of packaging material using advanced composite structures based on constituents derived from the food industry (cf Fig. 1). In the framework of this project, we aim at developing a Decision Support System (DSS) to help parties involved in the packaging design to make rational decisions based on knowledge expressed by the experts of the domain. The Decision Support System developed in this context aims at solving the dilemma of multi-criteria demands in the design of packaging for fresh produce. This DSS relies on the development of a querying system (i) able to store and maintain data in dedicated databases (which could be incomplete or imprecise) about packaging material characteristics (e.g. gas permeabilities, cost, transparency, mechanical properties, etc.) and fresh food parameters (e.g. respiration parameters, optimal storage conditions), (ii) allowing stakeholders to express their needs and requirements as queries addressed to the system databases, and (iii) retrieving the packaging materials ranked from the most to the least satisfactory according to the expressed requirements.

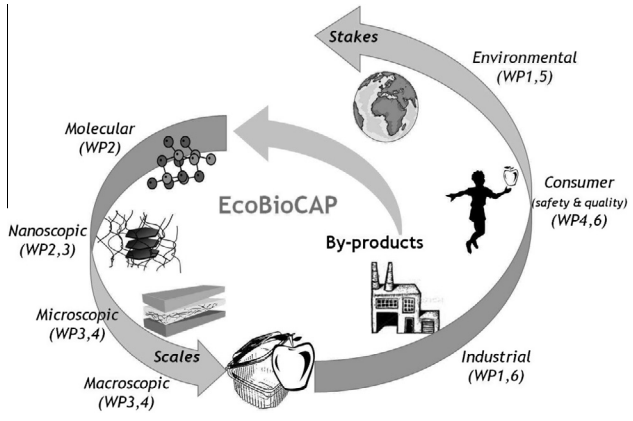

Fig. 1. The EcoBioCap project.

The original contribution of this paper is to detail the design and the implementation of the proposed flexible and bipolar multi-criteria querying system, part of the DSS for the EcoBioCap project:

- Functional description of the system based on the approach described in Destercke et al. (2011).
- Databases development and filling with food and packaging characteristics.
- Open source implementation with Java,[1] R for numerical processing,[2] and MySQL[3] relational database management system.

Functional specifications of the bipolar flexible querying system are introduced in Section 2. Its corresponding software architecture is detailed in Section 3. Implementation aspects and some tests are displayed in Section 4. Section 5 concludes the paper.

2. Functional specifications of the system

We detail here the main functions that the bipolar flexible querying system has to provide to the users. Prospective users of the EcoBioCap DSS have been identified in the Stakeholder Advisory Board of the EcoBioCap FP7 project.

Functional requirements implemented in the EcoBioCap DSS are the following:

1. Collecting and managing data available about the packaging material characteristics.
2. Collecting and managing data available about the respiration parameters of fresh produce.
3. Managing users' preferences expressed over packaging material targeted characteristics as constraints or wishes.
4. Dealing with missing data, since in real cases some required packaging characteristics could be unknown, so stakeholders of the food chain may face the problem of missing data.
5. Managing imprecise data, since characteristics associated with packaging materials (e.g. O_2 permeability values) and food products (e.g. maximal respiration rates) may be imprecise.
6. Retrieving the ranked list of all relevant packaging with their main characteristics.
7. Guaranteeing the retrieval of packagings which are the closest to the requirements (called guaranteed solutions) in case of empty set of solutions.

3. Architecture of the flexible querying system

Fig. 2 details the components of the developed flexible querying system implementing the required functionalities. Namely, (i) two databases (for fresh foods and packaging materials), (ii) the virtual MAP simulation and (iii) the multi-criteria flexible querying system.

3.1. Databases

The flexible querying system defines and implements two databases: (i) *fresh food* database containing the respiration parame-

[1] www.java.com.
[2] http://www.r-project.org.
[3] www.mysql.com.