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Towards precision food packaging by optimization

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ABSTRACT

This publication briefly introduces a modelling method for the shelf-life of foods used in VTT Biotechnology and Food Research, and a unique VTT Precision Packaging Concept, which has been developed in the institute.

The aim of modelling shelf-life is to determine the dependence of foodstuff shelf-life on several storage and packaging parameters and to create mathematical models to make shelf-life calculations easier. Different packaging and storage parameter combinations, each of which gives equally acceptable food quality at the end of the required shelf-life of the product, can be selected. Using an experimental design strategy, it is possible to take many factors and their interactions into consideration simultaneously using a small number of experimental runs.

The VTT Precision Packaging Concept is based on the known requirements for the package, product and storage of the product and each of their contributions to the shelf-life of the product. Several factors can be considered in the optimization process for packages covering, e.g., the performance in logistics, marketing properties, consumer convenience, costs, and environmental stresses. The importance of these factors is carefully considered along with the opinions of the food manufacturer, the packaging material manufacturers, the wholesaler and independent specialists. The VTT Precision Packaging Concept can be used as a tool in the decision-making process when launching new products. The general goal of the concept is to optimize the cost-effectiveness of the packaging process, e.g. source reduction of packaging materials, and environmental issues.

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Avainsanat food packaging, shelf-life, modelling, optimization

Tiivistelmä

Tässä julkaisussa esitellään lyhyesti VTT Bio- ja elintarviketekniikassa käytetty elintarvikkeiden säilyvyyden mallitusmenetelmä sekä VTT Bio- ja elintarviketekniikassa kehitetty ainutlaatuinen elintarvikepakkausten optimointityökalu: VTT Täsmäpakkaus -menetelmä.

Säilyvyyden mallitusmenetelmässä selvitetään erilaisten varastointi- ja pakkaustekijöiden vaikutus elintarvikkeen säilyvyyteen. Tämä vaikutus esitetään säilyvyyden ennustamista helpottavilla matemaattisilla malleilla. Lopuksi elintarvikkeelle saadaan määritettyä joukko erilaisia pakkaus- ja varastointiolosuhteiden yhdistelmiä, jotka ovat elintarvikkeen säilyvyyden kannalta tasavertaisia. Menetelmässä käytetään apuna tilastollista koesuunnittelua, jolloin otetaan huomioon useita elintarvikkeiden säilyvyyteen vaikuttavia tekijöitä ja niiden mahdollisia yhteisvaikutuksia pitämällä samalla kokeiden lukumäärä mahdollisimman pienenä.

VTT Täsmäpakkaus -menetelmän perustana on tieto pakkauksen, tuotteen ja varastoinnin aiheuttamista reunaehdoista tuotteen säilyvyydelle. Menetelmässä voidaan ottaa huomioon pakkaamisen, kuljetuksen ja varastoinnin aiheuttamia kustannuksia, kuluttajien asenteita, pakkauksen markkinointiominaisuuksia, sen logistista toimivuutta, lainsäädännön asettamia rajoituksia ja vaatimuksia sekä arvioida pakkaamisen aiheuttamia ympäristövaikutuksia. Edellä mainittujen tekijöiden merkitys painotetaan käyttäen hyväksi pakkausten valmistajien, pakkaajien, kaupan ja eri asiantuntijatahojen näkökantoja. VTT Täsmäpakkaus -menetelmän avulla voidaan pakkaamisesta aiheutuvia kustannuksia vähentää pakkauksen toimivuuden heikentymättä: tuloksena on kullekin tuotteelle räätälöity täsmäpakkaus.

PREFACE

VTT Biotechnology and Food Research began a three-year project entitled ‘Modelling and optimization of modified atmosphere food packages’ in 1994. The project was part of the Packaging technology programme of the Technology Development Centre (TEKES).

The aims of the project were:

1. to model the dependence of the shelf-life of gas- and vacuum-packed foodstuffs on several packaging and storage parameters (e.g. temperature, illumination, the gas space volume of packages, the concentrations of gases and the capacities of oxygen absorbers)

   and

2. to optimize gas- and vacuum-packages of foodstuffs and at the same time take into consideration the demands of logistics and cost savings.

Another aim was to help the food industry in choosing plastic packaging materials, and in considering the demands of logistics, cost savings and shelf-life and to improve competitiveness. An additional aim was to give packaging material exporters a method to optimize materials for the different conditions in the importing countries and to help the after-treatment of plastic-based packaging materials.

The project has been unique, even internationally rated. Elsewhere optimization methods for transport packages have been developed, but not for primary packages, which are in direct contact with foodstuff. This research gave extensive information on several of the packaging and storage parameters affecting the shelf-life of foodstuffs. During the development of the optimization concept VTT, the Association of Packaging Technology and Research (PTR) and other companies learned that the optimization of packages is difficult and problematic because different groups evaluated different components of packaging and logistics characteristics in various ways. The results of this research can help firms to produce rational packages and to focus attention on the appropriate areas of packaging.

During this project, VTT introduced a new term to the field of optimized packaging: precision packaging. In precision packaging, packages are optimized or tailored so that they give the packed products the required shelf-life in addition to being suitable for production and distribution, while minimizing both environmental stresses and costs and fulfilling consumer expectations. This publication gives a short description of the method of modelling shelf-life and the optimization of the food packages that were developed during this project. The foodstuffs studied were: roasted chicken balls, ham pizza, sliced cheese, raw chicken legs, rye bread and coffee powder.

The storage time and temperature are difficult factors to include in the modelling of the shelf-life of foodstuffs. Often these storage factors have such strong effects on the quality parameters of the foodstuff that the packaging factors used have only very minor effects on quality parameters. Therefore, it is important to perform a screening test first and then a more extensive modelling test. In the screening stage, all storage and packaging factors can be considered simultaneously. The aim of the screening stage is to identify the most important factors that cause substantial effects in the responses. After screening, in the more extensive modelling stage, factors have to be considered at each storage time-storage temperature point or at each temperature point (the probable storage temperatures) in order to get more information about how the packaging factors affect the quality parameters.

The packaging materials and techniques used nowadays for most of the evaluated products were found to be over-estimated. The transparency of the packaging material used for pizza and cheese was a critical factor affecting the quality of these products and sufficient attention should be paid to it. On the other hand, raw chicken legs are very sensitive to microbiological deterioration and it is extremely important to keep the storage temperature low enough (+2°C), because even a good package will not protect raw chicken meat from quality deterioration at too high a storage temperature.

During the research, package optimization was performed for all the products discussed above. A spreadsheet-based software ‘tool’ was developed to make optimization easier.

The composition of the packaging material does not affect the optimization result as much as the packaging technique used (flowpack, thermoformed tray, preformed tray, carton plate in flowpack). A deficiency in this research is the fact that it was not possible to take into account the environmental stresses resulting from packaging materials, because no accurate data were available. Environmental stresses are currently being determined by a life cycle assessment (LCA) in another study at VTT. When the results from the LCA study are available, the composition of packaging material may be a more important factor in determining the optimization result than it was in this study. In the future, more attention should be paid to consumer attitudes and expectations in the package optimization process.

This project was financed by TEKES, VTT and sixteen companies, which are either package manufacturers or users, or independent specialists of packaging technology and plastics industry. Mrs. Terhen Järvi-Kääriäinen from PTR was the chairperson of the management group. We wish to thank the financing companies and the members of the management group.

We would like to express our sincere thanks to all the research scientists and technical assistants from VTT, who partook in this project. We would also like to warmly thank Timo Pullinen M.B.A., M.Sc. from Bio Business Consulting, for reading the manuscripts and for his valuable comments. He also thought up the concept of ‘precision packaging’.

CONTENTS

LIST OF SYMBOLS

Factors	CO_2 = carbon dioxide concentration of package
	Il = illumination time
	O_2Ab = absorbing capacity of oxygen absorbers
	Ox = oxygen transmission rate of packaging material
	St = storage time
Statistics	MLR = multiple linear regression
	RSM = response surface methodology
	R^2 = coefficient of determination
	RSD = residual standard deviation
	Q^2 = cross-validatory coefficient of determination
Materials	EVOH = ethylene vinyl alcohol
	PA = polyamide
	PE = polyethylene
	PET = polyethylene terephthalate
	PP = polypropylene
	PS = polystyrene
Other	C_0 = constant
	$C_1...C_n$ = coefficients for factors
	ε = unknown effect
	I = coefficient for a package characteristic
	LCA = life cycle assessment
	$X_1...X_n$ = factors
	Y = quality parameter

1. INTRODUCTION

Package design has a great significance on the success of foodstuff nowadays. Packages are clearly an integral part of the manufacturing and distribution processes. As clothes speak for their wearers, so too packages speak for the packed food product. Packages are developed not only to make weekdays easier for the consumer, but also to make times of celebration more festive. Many food products would not be in shops and on dining-tables, if they have not been packed. Nowadays packages face difficult challenges and roles. They have to create the ambience that hitherto was forged by personal service. Packages replace the salesman.

In addition, packaging has many other functions and requirements which it has to fulfil more and more effectively and economically. These functions and requirements are changing all the time and their importance in ensuring the success of the product is growing. The aim is to make the optimal package, which sufficiently satisfies all the functional requirements in addition to meeting environmental and cost demands as well as possible. The answer to these complex demands is precision packaging.

Precision packaging is a new concept in the packaging area. Precision packaging is based on the pre-determined minimum shelf-life needed to allow the packed foodstuff to reach the consumer's table from the factory. The shelf-life is naturally chosen to suit the market and the business strategy of the company. A longer shelf-life is needed for an export market than for a home market. Depending on the business strategy, the company can favour either short or long best-before times. It should be noted that the selling time of the product does not necessarily have any other connection to the real shelf-life but, naturally, the selling time is always shorter than the shelf-life.

This publication gives a short description of the modelling of shelf-life and the optimization of food packages. At the end of the publication, one real example of modelling and optimization is given using gas-packed roasted chicken balls as the model foodstuff.

2. MODELLING SHELF-LIFE

This chapter first introduces factors affecting food quality and the modelling of shelf-life found in the literature.

From the beginning of the 1970s, there has been a need in the literature to express the dependence of food quality attributes on several storage and packaging factors with mathematical equations, i.e. models. Mathematical modelling of the shelf-life of packaged food is essentially a quantitative description of a system that consists of the food, the package and the environment (Gnanasekharan & Florors 1993).

Mathematical modelling of the shelf-life of packaged foods requires consideration of the mechanisms of food degradation, the effect of environmental factors on the packaged food, and an understanding of the properties (mass transfer, mechanical, sealing, etc.) of packaging materials (Gnanasekharan & Florors 1993). The numerous combinations of these factors (Table 1) make generalized analytical modelling complicated. The success of such an approach requires quantitative information on each system component. This is the reason why the majority of existing models are specific to certain foods or classes of foods. However, models describing deteriorative mechanisms in specific foods can be used for predicting the storage stability of similar foods with suitable modifications (Taoukis *et al.* 1988, Quast & Karel 1972, Lazarides *et al.* 1988). In the paper of Gnanasekharan and Florors (1993) the majority of models for processed foods concentrated on moisture and oxygen related deterioration. The effects of carbon dioxide and temperature/gas interactions must also be taken into consideration (Labuza *et al*. 1992). An ideal model should take into account all the factors affecting food quality in the product-packaging-distribution system (Gyeszly 1991).

Table 1. Some factors that should be considered during the modelling of packaged food shelf-life (Gnanasekharan and Florors 1993).

Deterioration due to	Deteriorative effect on foods	Type of packaging protection/function
Oxygen	Lipid oxidation, Vitamin destruction, Protein loss, Pigment oxidation	Oxygen barrier
Moisture	Nutritional quality loss, Organoleptic changes, Browning reactions, Lipid oxidation	Moisture barrier
Light	Oxidation, Rancidity, Protein and amino acid changes, Vitamin destruction, Pigment changes	Light barrier
Microorganisms/ Macroorganisms	Food spoilage, Nutritional and quality loss, Potential health hazard	Hermetic containment
Mechanical abuse (dropping, compression, vibration, abrasion and rough handling)	Organoleptic changes, Spoilage and other quality changes due to failure of seals, pinhole formation, etc.	Material and sealing properties
Odorous substances Toxic chemicals	Off-flavour formation, Taste deterioration, Chemical changes, Toxic hazards	Barrier properties, Chemical resistance
Tampering	Product loss, Quality changes, Potential heath hazard	Tamper proof/ evident/- resistant
Consumer handling, Abuse, Misuse	Product loss, Quality changes, Nutritional changes, Organoleptic changes	Mechanical properties, Clear information (labelling)

In order to interpret the shelf-life, it is necessary to determine the degree of deterioration which is just acceptable, the most rapidly deteriorating property or properties characteristic of the quality of the product (the so-called critical characteristic(s)) and the storage conditions influencing quality maintenance (Varsányi & Somogyi 1983).

2.1 Types of models

Two types of models are generally used to determine shelf-life: these can be referred to as discrete and continuous models (Varsányi & Somogyi 1983). Discrete models are employed primarily for studying the quality-influencing effect of the storage conditions. The procedure basically consists of comparing the characteristics of the product at various intervals during storage using statistical methods (mainly variance analysis) and determining the degree of quality change from the results (Gacula & Kubala 1975). Continuous models are based on determinations of the supposedly stochastic relationship between the storage period and the quality of the foodstuff. A continuous model is characterised by the numerical determination and statistical analysis of so-called deterioration curves (Gacula 1975).

Considering the process as a whole, discrete models provide less information with a relatively high degree of reliability, while continuous models provide more information, but with a parallel decrease in the reliability of the conclusions. The critical characteristic, i.e. the most rapidly deteriorating of the characteristic(s), can be determined after statistical analysis from either a discrete or a continuous model. The composition of the foodstuff, and the relative humidity of the atmosphere, the temperature, the packing material, and the method of packing and the light are considered to be the most important of the conditions tested (Varsányi & Somogyi 1983).

Two basic methods for the modelling of shelf-life can be found in the literature:

1. The formulation of a model by using existing kinetic equations for chemical degradation reactions and mass transfer equations for degradative compounds, and testing the validity of the 'theoretical' model with some practical experiments (theoretical modelling)

2. The contribution of a number of large storage tests with several quality-affecting factors one at a time and the fitting of the test results to suitable mathematical equations to describe the quality dependence on individual factors (experimental modelling).

The third, not much used, form of shelf-life modelling, however, according to published data, is carried out by establishing large storage tests with multivariable experimental designs and data processing to formulate overall shelf-life equations for the calculation of shelf-life.

2.2 Modelling based on multivariable experimental design

If a model of the simultaneous effects of several factors is needed, multivariable models must be utilized. The basic idea is to vary all relevant factors simultaneously according to an experimental design and to get the maximum amount of information from collected data in the fewest number of experimental runs. The basic types of multivariable model equations are the following:

linear $$Y = f(X_1, X_2, ..., X_n) = C_0 + C_1X_1 + C_2X_2 + ... + C_nX_n + \varepsilon$$

interaction $Y = f(X_1, X_2, ..., X_n) = C_0 + C_1X_1 + C_2X_2 + ... + C_nX_n + C_{12}X_1X_2 +$

$$C_{13}X_1X_3 + C_{23}X_2X_3 + ... + C_{1n}X_1X_n + ... + C_{n-1,n}X_{n-1}X_n + \varepsilon$$

quadratic $Y = f(X_1, X_2, ..., X_n) = C_0 + C_1X_1 + C_2X_2 + ... + C_nX_n + C_{12}X_1X_2 +$

$$C_{13}X_1X_3 + C_{23}X_2X_3 + ... + C_{1n}X_1X_n + ... + C_{n-1,n}X_{n-1}X_n + X_1^2 + X_2^2 +$$

$$+ ... + X_n^2 + \varepsilon$$

where Y is a certain quality parameter, $X_1 ... X_n$ are the factors, C_0 a constant and $C_1 ... C_n$ the coefficients for the factors. ε refers to the unknown effects and represents the noise terms of the model.

According to Gyeszly (1991), the appropriate modelling method for the shelf-life of an environmentally sensitive packaged food product is a total system approach. Modelling of the product, the packaging system, and the environment, enable identification of the optimal solution, which could change the product or the distribution. The system model is a decision-making tool, but the verification of the results is essential. The modelling cannot be developed without serious effort and the participation of several of the functions within the corporation. The packaging organization can start and lead activities, but without the full commitment of the entire corporation, shelf-life modelling cannot be successful.

2.3 VTT method for the determination of shelf-life

The modelling of the shelf-life of foodstuffs is performed in seven steps: 1) selecting factors and responses, 2) selecting the experimental design method (screening or more extensive method), 3) carrying out tests, 4) analysing results, 5) making shelf-life predictions, 6) determining the minimum package requirements and 7) determining different package and storage combinations.

2.3.1 Selecting factors and responses

First, all of the factors that might be relevant and might affect the quality deterioration of the foodstuff are chosen. The factor types can be quantitative (e.g. oxygen transmission rate of the packaging material) or qualitative (e.g. illumination). In addition, factors can be uncontrolled (e.g. outside temperature, machinery type), but in that case it has to be considered how to measure them or how to “block” them out of the experiment. Relevant factor levels are chosen.

In addition, responses, which could illustrate well the quality and/or the deterioration of the foodstuff, are chosen.

2.3.2 Selecting the experimental design

When factors and their effects on food quality are not very well known or when there are too many factors in the investigation, a screening experiment is carried out to select the most important factors. In the screening experiments, for example, Full Factorial, Fractional factorial, L-designs and Plackett-Burman designs can be used. After the screening experiment, the research is continued with a more extensive response surface methodology (RSM) investigation of the most important factors. The design used in RSM investigations can be, for example, a three-level full factorial design, a central composite circumscribed design or a central composite face-centred design. If results from the screening experiment are excellent, there is no need for any further investigation.

2.3.3 Analysing results and making shelf-life predictions

After the tests are carried out, the results are analysed. Multiple linear regression (MLR) is used to estimate the coefficients of the terms in the model. The MLR separately fits one response at a time. Mathematical models are then created and predictions are made. A model, including the set of linear, interaction and quadratic terms giving the best combination of R^2 (the coefficient of determination) and Q^2 (the cross-validatory coefficient of determination) and a satisfactory p-value for regression in ANOVA, is used for the evaluation of the behaviour of the responses as a function of the factors. Significant factors for the model can be selected by stepwise procedures. A forward stepwise technique selects, at each stage, the set of terms (= factors) which gives the best combination of R^2 and Q^2 and a satisfactory p-value. A backward stepwise technique first selects all the terms (= the full model) and then the least significant term is removed and this procedure is repeated until the model contains only significant factors.

The values of the factors used in calculations (models) must be expressed in the same units as those used in the statistical experimental design and they should be chosen from the range used in the study.

According to Pike (1986), multiple regression is an art, not a science. Of course, rules exist to assist the scientist, but the evaluation of an adequate representation of a response as a function of the many possible stimulus variables is a minefield for the unwary. The challenge is to effect a compromise between including enough terms in the model to obtain greater accuracy of prediction, and keeping the final model as simple as possible.

2.3.4 Determining the minimum package requirements and the different package and storage combinations

Finally, minimum packaging requirements can be determined. Different packaging and storage parameter combinations, all of which give equally acceptable food quality at the end of the required shelf-life of the product, can also be selected.

3. VTT METHOD FOR OPTIMIZATION OF FOOD PACKAGES

After the required packaging parameters for certain products and at certain storage conditions have been determined by modelling, it is then possible to optimize the packages for each foodstuff. Optimization can then be carried out using different combinations of package conditions all giving equally acceptable food quality at the end of the required shelf-life of a product.

3.1 Issues in package optimization

The basic aim in the optimization of food packages is to create a tool for decision-making policy for launching new products. This packaging optimization concept should not only advantageously help food manufacturers, but also packaging material and packaging manufacturers to evaluate and compare the feasibility of their new and present products. In today's competitive market, packaging innovation can be a big advantage in efforts to persuade the consumer to buy a certain brand, and the packaging optimization concept may help to reduce the economic support and time needed for package development.

Several factors should be considered in the optimization process for packages, covering the performance in logistics, marketing properties, consumer convenience, costs, and environmental stresses (Figure 1). The general goals in package optimization are the cost-effectiveness of the packaging process and environmental issues, e.g. source reduction of packaging materials. The importance of these factors is discussed below.

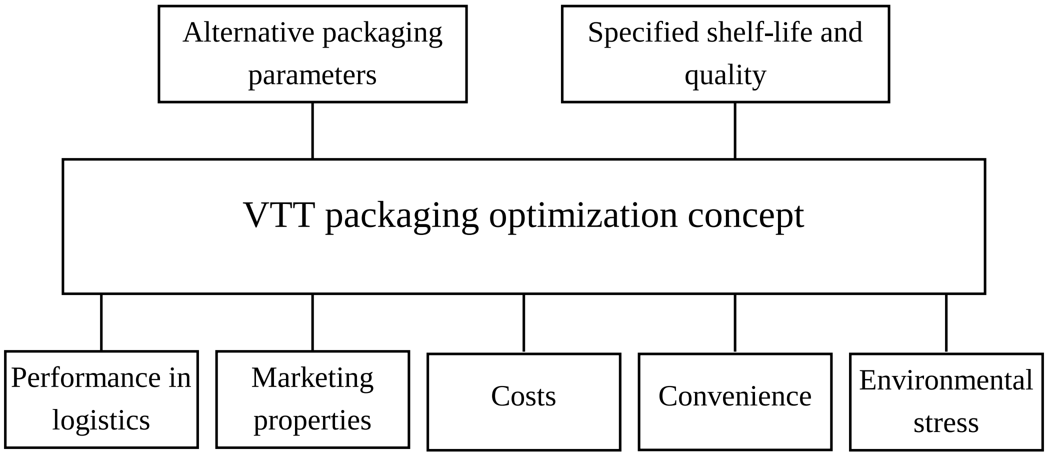

Figure 1. The VTT packaging optimization concept for food packages.

3.1.1 Performance in logistics

One of the most important tasks of a food package is to afford protection from environmental conditions, like oxygen, light and moisture. This is crucial for maintaining the quality and safety of most packaged foods. Therefore, it is essential that a package has sufficient mechanical strength to protect the packaged product from environmental stresses during distribution and storage. Environmental issues, however, demand that packaging material consumption is kept to a minimum and that packaging materials be recoverable. This requires the food industry to use thinner materials, which still have both sufficient mechanical strength and barrier properties. An optimized, downsized package may also reduce wholesaler and retailer costs. On the other hand, in some cases it may also be favourable to use relatively thick, recyclable monomaterial layers (e.g. PE) suitable for energy recovery. In other words, an optimized food package minimises the waste in the overall packaged product.

New packaging solutions should also be technically feasible. That is, they may not set any limitations on either packaging speeds or the quality of seals. Package dimensions need to be logistically congruent with the secondary package and pallet. The ratio of packaged product to package volume should be as high as possible.

3.1.2 Marketing properties

The marketing properties of a package should be fulfilled as well as necessary, not as well as possible. This means that, optimally and cost-effectively, only adequate investment is needed to fulfil the need for, e.g., package design in terms of packaging material consumption, decoration and information. Keeping up the brand image of a product should be taken into account when making packaging decisions. It is important that package designers, manufacturers and users can co-operate closely to achieve an optimum package.

3.1.3 Costs

From a food manufacturer's point of view, especially, the costs of primary packaging materials as well as indirect packaging costs (storage, transportation, energy consumption, and labour costs) should certainly be as low as possible. A cost-competitive package is, of course, a benefit for both the packaging and the food manufacturers. A packaging innovation requiring a minimum of investment and giving consumers products they like, at affordable prices, can be seen to be a very attractive goal. Such innovations could be, e.g., easy-open seals or thinner materials which consumers find more environmentally friendly.

3.1.4 Consumer convenience

Such properties of a package that make it convenient for the consumer include it being easy-to-handle, carry, store and dispose of/re-use, as well as its openability, resealability, and microwaveability.

3.1.5 Environmental stresses

Environmental aspects should be taken into account as well as possible in the optimized package. The relevant issues include the need for low environmental stresses from the packaging material and packaging (to be determined by a life cycle assessment in another study at VTT), the necessity of a low ratio of package weight to product weight, the need for as little of the package volume as waste as possible, and the incineration possibilities of different packaging materials. In this study, performed at VTT, the incineration and disposal possibilities rather than the reusability of the packaging material in contact with food were looked at as possibilities for plastic and metallized plastic materials. The reasons for this were national legislation aspects and the state of the power plants for municipal waste and the dumps.

3.2 VTT method for package optimization

Package optimization is performed in four steps: 1) scoring the tested package types, 2) evaluating the importance of package characteristics, 3) calculating the coefficients for each of the characteristics, and 4) calculating the optimization result of each of the tested package types.

3.2.1 Scoring the tested package types

The evaluated packages are first optimized by rating nine different characteristics of each package type giving the same minimum required shelf-life:

- Mechanical strength of a package
- Suitability with respect to packaging standards
- Ratio of package weight to product weight
- Volume of package waste
- Possibility of incineration
- Marketing properties of a package
- Consumer convenience
- Cost of packaging material
- Indirect packaging costs

All these characteristics are scored on a scale from 1 to 5, with 1 corresponding to poor and 5 to excellent quality. Fractional numbers are also allowed. The scoring is performed by VTT in co-operation with experts representing wholesalers, food manufacturers, packaging material manufacturers and independent specialists of packaging technology and plastics industry.

In addition, other package characteristics establishing information for the selection of packaging material and packaging type may be used in package optimization, for example, the environmental stresses of multilayer materials used in food packages, consumer attitudes towards new packages, and the possibility for just-in-time manufacturing (ease of frequent changeovers in the production line and increased productivity).

The **mechanical strength of a package** is determined using a simulated transportation test. In the test, a whole pallet positioned on a vibration table is subjected to a simulated road transportation of about 1000 km. As an example, during this 45-minute test run, the table is vibrated at a constant acceleration of 0.5 g, with the frequency of the table sweeping between 5 and 55 Hz. Since each package type resonates at its own specific frequency, every package tested is exposed to more or less high accelerations during the test procedure. In general, the packages in the top layer of a pallet are exposed to the highest accelerations, which can be even more than 6 g.

After the test, all the possible flaws, such as flexes, fractures, open seals and product disorientation originating from the transportation tests are recorded, and the test packages are scored as follows:

- 1 point: if even one tested package in the pallet is leaking, the whole sample group is rejected.
- 3 points: there are some minor dents or flexes.
- 5 points: no package is affected by the vibration test.

Suitability with respect to packaging standards is evaluated by examining the volume occupied by the primary packages tested in a secondary package, which had the dimensions of the pallet area. Scores between 1 and 5 are given on the following basis:

- 1 point: relatively large empty space left in the secondary package.
- 5 points: primary packages tight together, no empty space in the secondary package.

The score for the **ratio of package weight to product weight** is calculated on the following basis:

- 1 point corresponds to an empty package weighing 10% of the weight of the packaged product, and
- 5 points correspond to an empty package weighing 1% of the weight of the packaged product.

Volume of package waste is scored from 1 to 5 on the following basis:

- 1 point: a rigid package, e.g. tray, which cannot be scrunched and which would require a large space in a household waste basket.
- 5 points: a package that is made of a thin flexible material, which can easily be put in a household waste basket without the need for stuffing or scrunching.

The **suitability of the empty package for incineration** is evaluated as follows:

- 1 point: cannot be incinerated under any conditions, e.g. metal can.
- 2 points: can be incinerated in a plant specialised for problem waste.
- 3 points: can be incinerated in a plant for municipal waste.
- 4 points: can be incinerated in a power plant for fossil fuel resources.
- 5 points: can be incinerated in the home.

The **marketing properties of a package** are evaluated by awarding scores between 1 and 5 on the following basis:

- 1 point: package design or packaging material does not meet the requirements of brand/company image and logistics, poor printability, insufficient space for labels, poor visibility on the shelf.
- 5 points: excellent package design, proper packaging material, excellent printability, enough space for labels, excellent visibility of the packaged product on the shelf.

The **consumer convenience** of the package is evaluated by awarding scores between 1 and 5 points as follows:

- 1 point: package dimensions and sharp corners make it difficult to handle, carry, store and dispose of, it is difficult to open without a tool and/or spillage of the product, it is not resealable, and is not suitable for microwave ovens.
- 5 points: package is easy to handle, carry, store and dispose of/re-use, as well as being easy to open, and reseal, and is suitable for microwave ovens.

The scored **costs of packaging material** are calculated based on the annual production reports given by the food manufacturers and the corresponding cost information for the necessary primary packaging materials given by the different packaging material manufacturers. The cost of the packaging material is first scored by the food manufacturers, as follows:

- 1 point represents a packaging material cost that is far too high compared to the total manufacturing cost of the product, whereas
- 5 points equals a very economical ratio of packaging material costs to the total manufacturing cost.

For example, if the food manufacturers rate packaging materials costs of 0.2 FIM/package for a specified product as very economical whereas 0.8 FIM/package is far too expensive, 5 points would be awarded to 0.2 FIM/package, 3 points to 0.5 FIM/package and 1 point 0.8 FIM/package.

Indirect packaging costs are estimated by including storage, transportation, energy consumption and labour costs. The estimations are made qualitatively. That is, different package types (flowpacks, form-fill-sealed-packs, preformed trays) are ranked against each other on a scale of 1 to 5.

3.2.2 Evaluating the importance of package characteristics

After the characteristics of the tested packages have been scored, the importance of the characteristics are evaluated by the food and packaging material manufacturers, the wholesaler and independent packaging technology and plastics industry specialists. As an example, the importance of the characteristics evaluated by the food and packaging material manufacturers is presented in Figure 2.

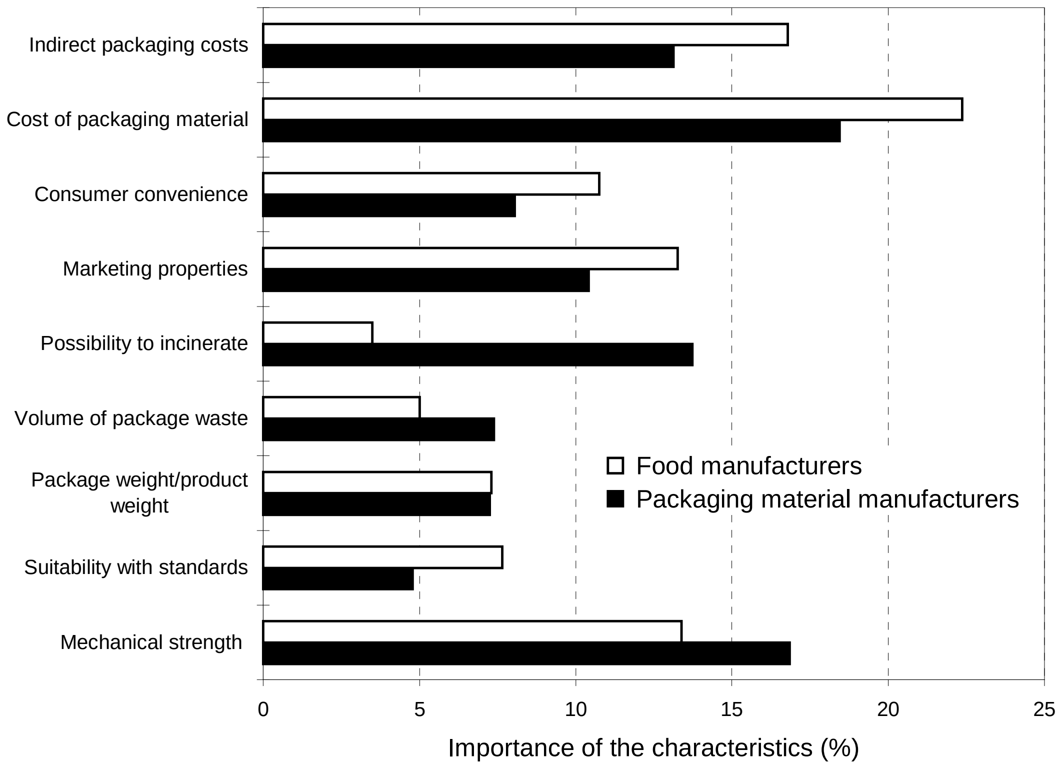

Figure 2. The importance of the various characteristics of packages evaluated by 5 Finnish food manufacturers and 8 packaging material manufacturers (mean ratings).

3.2.3 Calculating the optimization result

The coefficient, *I*, for each of the nine characteristics is then calculated using the following ratings: 1) the importance of a given package characteristic as evaluated by the food manufacturer of the product, 2) the mean rating for the importance of the package characteristic as evaluated by the packaging material manufacturers of the product, 3) the importance of the package characteristic as evaluated by the wholesaler, and 4) the mean importance of the package characteristic as evaluated by the independent specialist for the packaging technology and plastics industry. These four ratings are then multipled by the corresponding coefficients agreed with all the participants referred to above and VTT.

The optimization result of a certain tested package type is then calculated using the scores given to each of the nine characteristics and the coefficients. This procedure not only enables the evaluation of the particular tested package types, but it also serves as an estimation tool for subsequent packaging innovations. It is also possible to ignore some characteristics, and calculate the optimization result with, for example, only seven characteristics. In fact, this is the case in the examples in the Chapter 4. That is, in an optimized package, the mechanical strength of a package and its suitability with respect to packaging standards are considered as the essential characteristics that all the packages should fulfil before being launched. Therefore, these characteristics can be ignored when calculating the optimization result.

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4. EXAMPLE

4.1 Description

The following example illustrate the modelling of the shelf-life of foodstuff and package optimization. This simplified method includes the elements that are presented in Figure 3. The tested foodstuff is gas-packed roasted chicken balls.

The method for modelling the shelf-life is presented in Section 2.3. The first stage of the study is the determination of the dependence of the quality of the foodstuffs on several packaging and storage parameters and to create mathematical models to make shelf-life calculations easier. The experimental designs were created by Modde software, which was developed by Umetri Ab (Sweden) for the experimental design and the graphical presentation of test results. After the required packaging parameters for certain foodstuffs at certain storage conditions are determined by modelling, it is possible to optimize the packages for each foodstuff. This package optimization method is presented in Section 3.2. The packaging material properties and the gas compositions in the package headspace were chosen to give the packaged foodstuffs the required shelf-life at the specified storage conditions. The mechanical strength of the package and its suitability with respect to packaging standards were ignored when calculating the optimization result.

Selecting the foodstuff:
- packaging and storage factors and their levels
- quality parameters
- experimental design method

↓

Carrying out tests

↓

Analysing results & Making shelf-life predictions

↓

Determining the minimum package requirements for the foodstuff
(certain storage conditions)

↓

Alternative packaging and storage combinations

↓

Package optimization

↓

OPTIMAL PACKAGE

Figure 3. A simple scheme for determining the optimal package for a given foodstuff.

4.2 Gas-packed roasted chicken balls

Minced chicken balls belong to the group of ready-to-eat foods that are supposed to be heated before eating. The cured prepared foods typically have low initial microflora levels and they are very sensitive to post-preparation contamination. Unpacked and air-packed cooked minced meat or poultry products usually spoil due to yeast and mould growth. The growth of these micro-organisms can be strongly retarded by using gas-packaging (Ahvenainen 1989).

4.2.1 Materials and methods

The ingredients of the chicken balls were minced chicken meat, onion, breadcrumbs, potato, soy protein products, egg, potato flour, vegetable oil, salt, powdered chicken soup, seasonings, glucose and flavour intensifier. The last day for use is 10 days after packaging when the storage temperature is kept below +6°C. Each package contained 400 g of chicken balls.

According to the results of the screening experiment, the headspace volume had no significant effect on the quality parameters of chicken balls, and it was omitted from the RSM investigations. The RSM investigations were carried out in two different test series. In the first test series, carbon dioxide and nitrogen were used in package head-spaces and in the second test series, the packaging gas used was normal air. In both test series the experimental design included 29 tests. The factors studied are shown in tables 2 and 3. The storage temperature was 6°C.

Table 2. The factors and factor levels studied in the first test series (modified atmosphere packages).

FACTOR	SYMBOL	FACTOR LEVELS
Storage time (days)	St	3 - 10 - 17 - 24 - 31
Carbon dioxide concentration of package (%)	CO_2	0 - 30 - 60
O_2 transmission rate of packaging material (cm^3/m^2d)[1]	Ox	2.2 - 105 - 1440
Illumination time (days)	Il	0 - 2 - 4

[1] = 23°C, 50% RH, 101.3 kPa

Table 3. The factors and factor levels studied in the second test series (air packages).

FACTOR	SYMBOL	FACTOR LEVELS
Storage time (days)	St	3 - 10 - 17 - 24 - 31
Absorbing capacity of oxygen absorber (cm^3)	O_2Ab	0 - 30 - 60
O_2 transmission rate of packaging material (cm^3/m^2d)[1]	Ox	2.2 - 105 - 1440
Illumination time (days)	Il	0 - 2 - 4

[1] = 23°C, 50% RH, 101.3 kPa

The quality parameters measured are shown in Table 4.

Table 4. The quality parameters measured in the chicken balls test series.

QUALITY PARAMETERS
Sensory analysis[1]:
- appearance
- odour
Microbiological analyses:
- aerobic plate count (log cfu/g)
- yeast and mould count (log cfu/g)
- coliformic bacteria count (log cfu/g)
- percentage of mouldy packages
Volume change of package

[1] = evaluated by a laboratory panel of 10 members using a quality scale from 1 to 9 (1 = major defects, totally changed; 9 = excellent, no defects)

4.2.2 Results of modelling

Provided that the chicken balls did not become mouldy, there was no significant change in odour or appearance of the product in either of the test series during a 1 month storage period. The most critical quality parameter affecting the acceptability of chicken balls was yeast and mould growth. Carbon dioxide and oxygen absorbers inhibited the growth of micro-organisms. Microbial growth was the slowest when the oxygen transmission rate of the packaging material was about 10 - 100 cm^3/m^2d.

In both test series useful mathematical models were obtained for aerobic plate count, yeast and mould count and the volume of the packages. In the second test series, useful models were obtained also for appearance, odour and coliformic bacteria count of chicken balls and for the percentage of mouldy packages.

Storage time was the most important factor affecting all the responses. The effect of illumination time on the quality of chicken balls was negligible in both test series.

In Tables 5 and 6 the models are used to predict possible combinations of oxygen transmission rate of packaging material and either carbon dioxide concentration in modified atmosphere packages (Table 5) or the absorbing capacity of oxygen absorber in air packages (Table 6).

Almost any kind of packaging can be used to achieve seven days shelf-life. When using high carbon dioxide concentrations in modified atmosphere packages or an effective oxygen absorber in air packages it is possible to use higher oxygen transmission rates of packaging material. High carbon dioxide concentrations may, however, decrease package volume and commercial acceptability. The packaging material does not need to provide light protection.

Table 5. The combinations of different carbon dioxide concentrations and oxygen transmission rate of packaging material that prevent microbial growth in chicken balls under preset limits for 7, 14 and 21 days storage. Illumination is not included in the aerobic plate count model, and in the yeast and mould model illumination time is 2 days. Nitrogen is used as a filling gas in the packages.

		Oxygen transmission rate of packaging material (cm^3/m^{2}d)	
Storage time (d)	CO_2 (%)	Aerobic plate count (log(cfu/g)) < 7	Yeast and mould count (log(cfu/g)) < 5
7 days	0	10 - 1000	10 - 1000
	30	10 - 1000	10 - 1000
	60	10 - 1000	10 - 1000
14 days	0	10 - 1000	< 530
	30	10 - 1000	10 - 1000
	60	10 - 1000	10 - 1000
21 days	0	< 50	< 100
	30	10 - 1000	< 640
	60	10 - 1000	10 - 1000

Table 6. The combinations of the absorbing capacity of oxygen absorbers and oxygen transmission rate of packaging material that prevent microbial growth in chicken balls under preset limits for 7, 14 and 21 days storage. Illumination time is not included in the models. The packaging gas is normal room air. (– = not possible).

		Oxygen transmission rate of packaging material (cm^3/m^{2}d)	
Storage time (d)	Oxygen absorbing capacity (cm^3)	Aerobic plate count (log(cfu/g)) < 7	Yeast and mould count (log(cfu/g)) < 5
7 days	0	10 - 1000	10 - 1000
	100	10 - 1000	10 - 1000
	200	10 - 1000	10 - 1000
14 days	0	10 - 1000	-
	100	10 - 1000	< 340
	200	10 - 1000	10 - 1000
21 days	0	10 - 1000	-
	100	10 - 1000	-
	200	10 - 1000	< 160

4.2.3 Results of optimization

Three packaging types were tested: flowpacks, trays thermoformed just before packaging, and preformed trays. The most important factors affecting the optimization result were indirect packaging costs, cost of packaging materials, and marketing properties (Tables 7 - 8). The results indicate that flowpacks obtained the best scores, especially in terms of packaging material costs and indirect packaging costs. The marketing properties of the flowpacks, however, were not evaluated as being as good as the properties of the other package types in general. Leaking seals were found in one type of flowpacks, and from one type of preformed trays. Therefore, a modification in package/packaging material structure should be made before the mechanical strength of these package types will be at an acceptable level.

To compare the best rated flowpack (Package 1), thermoformed tray (e.g. Package 5) and preformed tray (Package 6), the following estimations can be made. If the annual production of the product is 1 million packages, the annual savings in package material consumption for Packages 1 and 5 are 20 000 kg and 8 000 kg, respectively, when compared to Package 6. Similarly, the annual savings in packaging material costs for Packages 1 and 5 are about 290 000 FIM and 190 000 FIM, respectively, when compared to Package 6.

Table 7. Gas-packed roasted chicken balls: packages used in the 400 g package optimization. Secondary package: an open plastic stackable and reusable box. tffs = thermoformed tray/fill/seal.

Feature	Package 1	Package 2	Package 3	Package 4	Package 5	Package 6	Package 7	Package 8
Package type	flowpack	flowpack	tffs	tffs	tffs	preformed tray	preformed tray	preformed tray
Monomaterials used in package	PET, PE, EVOH	PE, PET	PA, PE	PA, PET, PE	PA, PET, PE, EVOH	PA, PE, PP	PA, PE, PP	PE, PS, EVOH
Package volume (cm^3)	≈1000	≈1000	≈800	≈1000	≈1100	≈1300	≈1200	≈1500
Weight of an empty package (g)	6	7	10	22	18	26	27	42
Transparency	clear	clear	clear lid and tray	clear lid and tray	clear lid, yellow tray	clear lid, opaque tray	clear lid, opaque tray	clear lid and tray

Table 8. Gas-packed roasted chicken balls: optimization results for the 8 different package types presented in Table 7. The scores given to the mechanical strength of a package and its suitability with respect to packaging standards have been ignored.

		Scores							
Characteristic	*I*	Package 1	Package 2	Package 3	Package 4	Package 5	Package 6	Package 7	Package 8
Mechanical strength	*0.10*	*5*	*1*	*5*	*3*	*5*	*3*	*5*	*1*
Suitability with respect to standards	*0.09*	*5*	*5*	*5*	*3*	*3*	*3*	*1*	*3*
Package weight/product weight	0.07	4.7	4.6	4.3	3	3.4	2.6	2.4	0.8
Volume of package waste	0.07	5	5	4	3	3	1	1	1
Possibility of incineration	0.07	3	3	3	3	3	3	3	3
Marketing properties	0.14	2	2	1.5	3	2.5	3	2.5	3
Consumer convenience	0.10	3.5	3.5	2	2.5	2.5	3.5	2.5	3
Cost of packaging material	0.14	5.14	5.57	5.53	4.33	4.5	3.7	3.15	0
Indirect packaging costs	0.23	5	5	3	3	3	2	2	2
Optimization result		**3.4**	**3.4***	**2.6**	**2.6**	**2.6**	**2.2**	**1.9****	**1.5***

* Packages 2 and 8 failed the simulated transportation test and, therefore, they were not acceptable.

** The dimensions of Package 7 were not suitable for the secondary package used for the product.

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