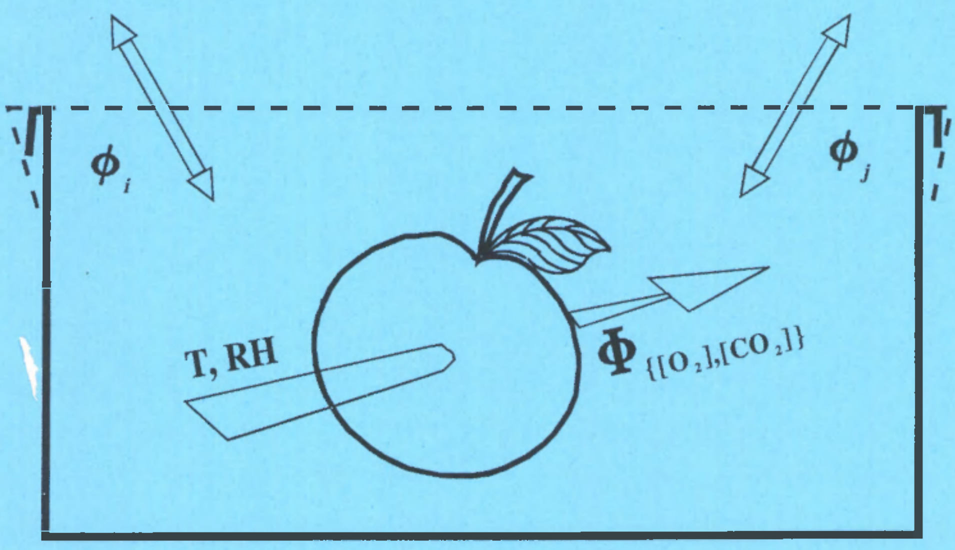
MASTER



1. PROJECT TITLE:

Modified Atmosphere Systems in varying TEmperature Regimes

EC-AIR PROJECT N^O AIR2-CT-1326

MIDTERM ASSESSMENT
JANUARY 1994 - OKTOBER 1995

Content

Summary

I Project title:
Modified Atmosphere Systems in varying TEmperature Regimes (MASTER)

II Organisations involved:
- P1: ATO-DLO (Agrotechnological Research Institute - Agricultural Research Department), NL-6700 AA Wageningen, coordinator
- P2: INRA (Institute National de la Recherche Agronomique), station de Technologie des Produits Végétaux, F-84143 Montfavet
- P3: Istituto di Industrie Agrarie, University of Pisa, I-56124 Pisa
- P4 FhILV (Fraunhofer-Institut für Lebensmitteltechnologie und Verpackung), D-80992 München, project management
- P5: VBT (Verbond van Belgische Tuinbouwveilingen), B-3000 Leuven
- P6: Istituto di Tecnologie Agro Alimentari, University of Tuscia, Viterbo, I-01100 Viterbo

III Scientific objectives

The MASTER project (Modified Atmosphere Systems in varying TEmperature Regimes) serves the overall objectives

* to show that the behaviour of the systems produces / packages may be modelled and that the shelf life of fresh produces may be extended by Modified Atmosphere Packaging (MAP) **in a predictable way**
* to develop a computer program together with an appropriate data base to simulate storage under MAP conditions for a selected range of products, temperatures and MAP packaging systems, thus allowing for a proper design of MAP systems according to the products and the temperature conditions of storage / distribution.

In more detail, the scientific objectives are
* to obtain a quantitative knowledge on respiration / gas - water vapour - exchange characteristics of typical products (selected: apples, tomatoes, chicory endives) in dependence on
  - initial status
  - ambient gas conditions
  - temperature
* to obtain data on gas and water vapour permeability of selected packaging film materials (selected: Polyethylene, Polyvinylchloride, Polystyrene, Ethylene - Vinylacetate - Polyethylene Copolymer, Polyester-Polyether Copolymer, Poly-(ε)-Caprolactone, Cellulose acetate, Cellulose, microperforated Polypropylene)
  in dependence on
  - gas species
  - temperature
  - humidity, humidity difference across the films,
* to combine the facts obtained on products and packaging in an appropriate data base,
* to develop a computer program capable of simulating the combined product / packaging behaviour in dependence on temperature profiles (the MASTER program)
* and to verify the applicability of the model for selected product / packaging combinations.

IV Discussion of work and achievements before the midterm assessment of the project

* Measurements on the behaviour of products (respiration, internal gas transport characteristics) at various temperature have been performed
* Measurements of packaging films (gas and water transport characteristics) at standard conditions have been performed
* Measurements on MA packages stored at various have been performed
* Object oriented design and development of MASTER model

to demonstrate

- the Michaelis Menten description for the respiration is feasible.
- the accessibility of the systems under study to numerical modelling
- the general viability of the envisaged software program

and to begin the collection of the numerous data for the data base on product and packaging material associated with the modelling software.

The results for the products show that

* the best normalisation parameters of the individually different products are their initial respiration rate at standard atmospheric conditions and at anoxic (0 % O_2, 0 % CO_2 and 100 % N_2) conditions
* maximum observed respiration rates show an Arrhenius type of temperature dependence for aerobic respiration (about 50 KJ mol^{-1} activation energy) and for alcoholic fermentation (about 25 kJ mol^{-1} activation energy),
* respiration rates in dependence of oxygen partial pressure can be described by Michaelis Menten kinetics,
* maturity effects of the respiration activity for chicory.
* skin permeability of apples appears to be very high compared to packaging materials concerned, activation energy of skin permeability is about 10 KJ mol^{-1}

The results for the packaging films:

* Gas and water vapour permeability's show an Arrhenius type of temperature behaviour, with activation energies ranging from 19 KJ mol^{-1} (Poly-(ε) caprolactone) and 61 KJ mol^{-1} (EVA/PE/N2), exception: microperforated PP.
* Water vapour permeabilities in the first order show a dependence on absolute water concentration difference across the film. As a second-order effect temperature dependencies are observed for which analytical expressions still have to be derived.

For available measurement equipment, initial difficulties were higher than expected. Respiration and gas permeation measurement equipment had to be redesigned and built-up at all partners.
The resultant time lag was compensated by an appropriate extension of measurement capacity beyond the original scope of the project.

The results for the MA packages show that

* The gasconditions inside a package can be measured.
* The MASTER model is in principle be able to describe the oxygen an carbondioxide inside MAP at various temperatures.

V Conclusions

* All parameters of the systems under study which are needed for modelling are experimentally accessible.
* The original concept for computer simulation program and related data base is valid.
* The project is within its intended frame of results, time and effort.

Chapter 1: Introduction

1.1 Overall objectives (total project period)

The overall aim of the project is to **provide an scientifically based approach** to predict the behaviour of fruits and vegetables in Modified Atmosphere Packaging (MAP) in a quantitative way, thus allowing for a more focused and wider application of MAP in packaging of fresh products resulting in a higher shelf life.

This approach is to be transformed into **a computer program**, capable of simulating the behaviour of the system packaging / packed goods / ambient temperature / time, thus enabling prospective users to properly select packaging materials and to properly design MAP packaging according to the requirements of products and storage / distribution conditions.

1.2 Detailed objectives (total project period)

To fulfil the overall objectives, the following detail objectives have to be reached: (due to the scope of the project for the indicated number of model products and packaging materials):

* Respiration and gas transport properties in dependence on initial status, ambient gas concentration and temperature are to be described quantitatively for 3 model products (apples, tomatoes, chicory endives)
* Gas and water vapour transport properties of 9 selected packaging materials are to be described quantitatively (Polyethylene, Polyvinylchloride, Polystyrene, ,microperforated Polypropylene, Ethylenevinylacetate / Polyethylene-Copolymer, Polyester/Polyether-Copolymer, Poly(ε)-Caprolactone, Cellulose acetate, Cellulose) in dependence on gas species (CO_2, O_2, C_2H_4), relative humidity, humidity gradient across packaging films and temperature.
* A computer program for simulating the gas composition inside a package in dependence on products, packaging material and storage / distribution conditions is to be set up, together with an (extendible) data base on products and packaging materials.
* The program / data base ability is to be verified experimentally.

1.3 Workplan / expected achievements (midterm assessment)

The MASTER project shows a systems oriented approach. It contains an experimental part and a modelling part. The work will be carried out in 11 tasks. The relation between these tasks is given in figure 1 of this chapter. Table 1 gives an overview of the tasks and the allocation in the course of the four years of the project.

Milestones for the midterm assessment as given in the Technical Annex:
This assessment is to be made against the satisfactory completion of the following programme items:

- *collection of 140 respiration rates values*
  An overview of the collected respiration rate data is given in table 2 chapter 3. For chicory, tomatoes and apples 51, 12 and 78 product-temperature- gascombinations conditions have been measured respectively. Thus by measuring 141 product-temperature-gascondition combinations the aim of 140 respiration rate values has been reached.
- *the modelling of the respiration should either be based on mathematical expressions based on chemical-physical and biophysical relations or on traditional methods.*
  The statistical analyses of the respiration rate data supports the biochemical relations (Michaelis Mentens kinetics) for the respiration with explained parts up to 85%.

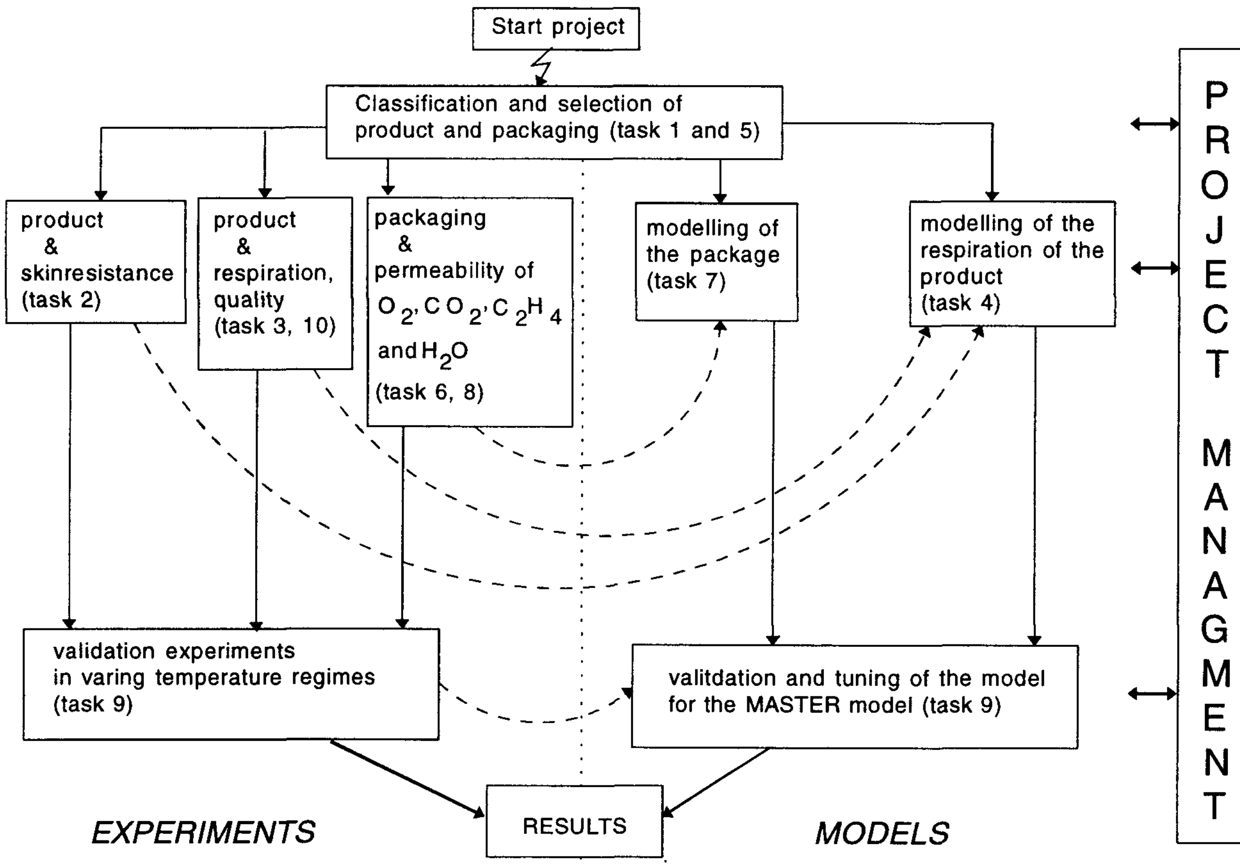


Figure 1: Structure of experimental and modelling tasks in MASTER

- *collection of permeation characteristics of 6 packaging materials.*
  The schedule of the measurements of the packaging materials has slightly been altered. Instead of doing all (standard and non-standard conditions) at one time and subsequently testing all films the schedule has been altered to start with all standard conditions for all films and subsequently the non standard conditions for all films. The permeation characteristics of all nine packaging materials has been obtained under standard conditions. This indicates that the activities of the packing material is on schedule.
- *With the MASTER model one should be able to validate the performed experiments in tasks 9 at a fixed temperature. Large deviations of the results calculated by the model should be attached to missing modules in the programme. These modules should be developed in the second part of the project.*
  Packaging experiment with chicory at 21, 16, 11 and 6 °C have been performed. The results of the experiments with the PE film have been selected as a test case for the MASTER model. The CO_2 inside the package is well described by the model. For O_2 deviations of 2% in the concentration have been found. It was discussed that this deviations is reasonable with respect to product variations. Furthermore it is expected that the deviation will become even somewhat smaller by the incorporation of the anaerobic respiration and a more reliable parameters for the respiration model due to the growing dataset.

Summarizing the activity of all time under investigation are on schedule and the project is carried out according plan.

Table 1: Timeschedule of the workplan and allocation of the resources

Task	Title	1st year	2nd year	3rd year	4th year
1	Survey and selection of agricultural produce	P2, P5, P6			
2	Gas transport in the produce	P3	P3	P3	P3
3	Respiration rate as a function of the surrounding gascomposition and temperature	P2, P3, P5	P2, P3, P5	P3, P5	P3, P5
4	Modelling of the respiration rate	P1	P1, P6	P1, P6	P1, P6
5	Survey and selection of the packaging materials	P4			
6	Temperature dependent gas and water permeability constants	P4	P4	P4	
7	Modelling the diffusion process through the packaging material	P1	P1	P1	P1
8	Building databases		P4	P4	P4
9	Evaluation of the whole system, for selected packaging and product	P1, P5	P1, P5	P1, P2, P5	P1, P2, P4, P5
10	Maturity effects on the respiration rate		P5	P5	
11	Project management	P4	P4	P4	P4

P1: ATO-DLO P2:INRA P3: Univ. of Pisa
P4: FhILV P5: VBT P6: Univ. of Tuscia

Chapter 2: Materials and Methods

2.1 Produces and their characterisation

Produces to be packed in modified atmosphere systems (selection for the project: apples, tomatoes, chicory endives) are to be characterised by the properties

- Oxygen respiration rate (uptake)
- Carbon dioxide respiration rate (formation)
- Ethylene formation rate
- Skin permeability's for gases (gas exchange properties)
- initial product status (colour, mechanical properties, initial respiration rates)
- final product status / experimental stop criteria:
  product weight loss and
  → either: quality below any acceptable limit (e.g. mould)
  → or: max. measurement time of 14 days exceeded

2.2 Characterisation of ambient atmosphere conditions

Parameters to be monitored are:

- O_2 partial pressure: 0.3, 10.1, 21.3 kPa
- CO_2 partial pressure: 0.5, 10.1, 15.2, 20.3 kPa
- relative humidity (close to 100 %, but condensation to be avoided)
- temperature.

Measurement and control of **gas composition** is performed in two ways:

- Measurement and control via gas chromatography (also for C_2H_4)
- Measurement and control via infrared sensors (CO_2) and paramagnetic sensors (O_2), capable of working in continuous closed circuits

Water vapour partial pressure (relative humidity) is generally obtained by controlled dehumidifying / humidifying.

2.3 Measurement of combined behaviour of produces and ambient conditions ("respiration measurements"), general principles

Here, the precept values of O_2/CO_2 partial pressures, relative humidity and temperature give the basic parameters.

The activity of the packed produce consists of
- the aerobic respiration (given by the net oxygen uptake)
- the alcoholic fermentation (given by the difference of overall CO_2 formation and oxygen uptake)
- ethylene formation
- and water release, given by the difference of the total weight loss of the products and the carbon losses via to CO_2 formation.

For the first two activities, gas compositions can be monitored by both methods indicated in 2.2.
For ethylene formation, only gas chromatography is appropriate.

2.4 Packaging materials and their characterisation

Packaging materials to be used for MAP are generally film materials of high, but limited permeability.
Their purpose is fivefold:

•The released CO_2 (due to product respiration) is to be accumulated inside the packaging to reduce respiration rate, but gas exchange has still to be high enough

•to admit O_2 to allow for a reduced respiration and

•to release excess CO_2 in order to avoid "bombing" of the packages.
•Water release through the packaging films has
• to be high enough to prevent condensation, mould, fouling, ... but,
• to be low enough to prevent excessive dehydration of products.

Although not all materials show optimum conditions for these purposes, the selection shown in chapter 3, task 5 has been made.

For the purposes of MAP and the simulation program to be developed in this project, the following data have to be obtained

- Permeability of materials for CO_2, O_2, C_2H_4 in dependence on temperature and relative humidity
- Permeability of materials for water vapour in dependence on temperature and relative humidifies on both sides of the films.

2.5 Measurements on packaging material properties

As to be seen from 2.4 and the individual progress report from P4, the measurement conditions have to be close to realistic conditions. This is rarely the case for available measurement equipment:

* **manometric/volumetric gas permeability measurement systems** are fast, useful **for all gases** and a large range of temperatures, but not gas specific and not operable under controlled relative humidity conditions

* gas specific carrier gas methods are obtainable **only for O_2 and CO_2.**

  For O_2, humidity may be controlled, for CO_2, only dry conditions can be applied.
* Water vapour permeation measurements (be it gravimetric or electrolytic detection of the permeated water) usually require a large relative humidity gradient across the films (typical: 85 % on one side, 0 % on the other). These conditions therefore do not represent ranges typical for MAP.

As a solution, standard equipment is used only for the first determination of overall values and of activation energies through temperature dependent measurements.
Corrections for the actual behaviour over the whole field of gas conditions will be obtained by specific measurement cells established at P4, also to be used in 2.6. Water vapour transmittance measurements at various humidities are made by a modification of a gravimetric method.

2.6 Measurement on the combined behaviour of produce, atmosphere inside packaging, packaging materials, atmosphere outside packaging, temperature.

For this purpose, specific integrated measurement cells (see figure 2), which existed at P1 and have been built at P4, will be used. The partners P2 and P5 will perform packaging experiments with packages that are close to commercially applicable systems.

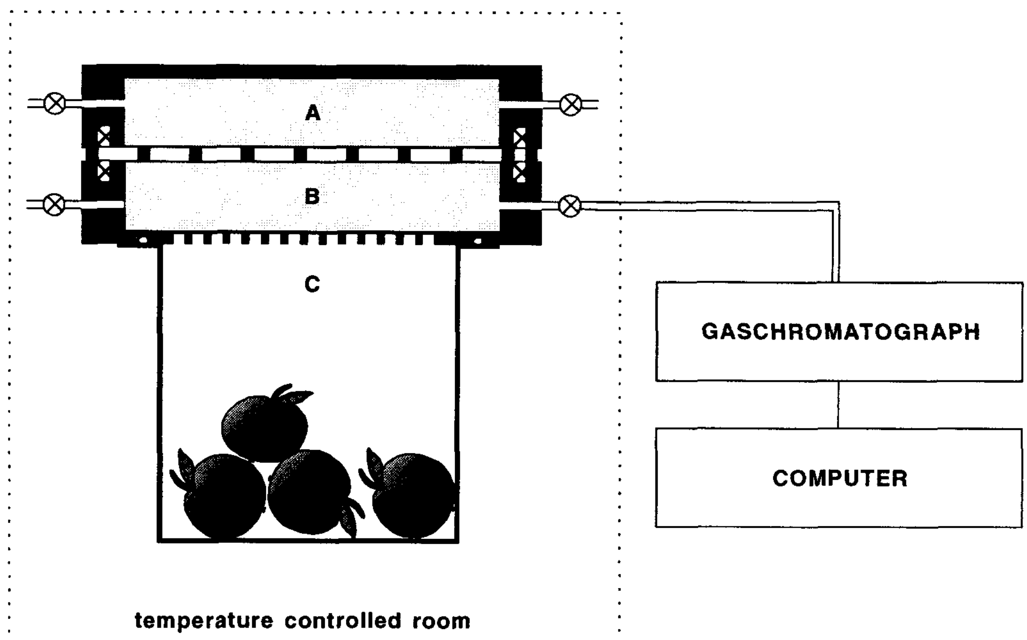


Figure 2: Schematic representation of the model packages

The basic principles of these measurements are:
- to maintain a controlled gas compositions inside the "packaging" (i.e. container covered with packaging film)
- to maintain an atmospheric gas composition outside the "packaging" (i.e. in the container head space, above the packaging film material)
- and to follow the respiration and gas exchange process via a continuous monitoring / restoring of the gas compositions

2.7 Modelling of the combined behaviour of produce, atmosphere inside packaging, packaging, atmosphere outside, temperature

For this purpose, the main goal of the project, formal descriptions will be used which describe - as close as possible - the actual biochemical / physico-chemical steps concerned.

These are:

_Produces are classified by their species and their initial respiration activity

_Respiration rates are treated as activated processes with an Arrhenius temperature behaviour and a gas partial pressure dependence according to Michaelis-Menten kinetics. Reaction pathways and rate-determining steps are to be included.

_Gas permeation rates are also treated as activated processes with Arrhenius behaviour both for skin permeability's of produce as well as for material and gas specific permeability's of packaging films.
_The relative humidity dependence both on gas permeability's as well as on water vapour permeability is to be interlinked with the sorption characteristics of the film materials for water.
_Actual packaging systems are modelled by their volume, surface, amount of packed goods, packaging material thickness.
_Storage and distribution conditions are modelled in terms of temperature vs. time profiles.

2.8 Strategies for co-ordination of the work of the participants

Co-ordination of the various activities is by regular group meetings and bilateral discussions. On average there is each 6 months a groupmeeting sceduled. Bilateral discussion have been more frequently. The relation between the tasks in the project is given in figure 1.

A major aim has been to decouple the work at different partners as far as possible and to interrelate the measurement series by means of **reference measurements.** The **main product responsibility** for apples, therefore, has been given to PISA, that for tomatoes to VBT and that for chicory to INRA. The **packaging material responsibility** has been given to FhILV and the **modelling responsibility** is given to ATO-DLO.

Chapter 3: Results

In the following a description of the work performed and the achievements obtained in the first year of the project are given for the various tasks addressed.

Task 1: Survey and selection of the agricultural produce.
The products chosen are:
* apples (Golden Delicious)
* tomatoes (round)
* chicory endives (witloof shoots)

to cover the range of respiratory activity typically observed for MAP-related products.

Temperature chosen for investigation were:
apples: 1 °C, 6 °C, 11 °C, 16 °C, 21 °C
tomatoes: 8 °C, 13 °C, 18 °C, 23 °C, 28 °C
chicory endives: 1 °C, 6 °C, 11 °C, 16 °C, 21 °C
to include the practically relevant temperature range and to go somewhat beyond this to allow for consistency checks at boundary conditions.

Task 2: Gas transport in the product
The gas transport in the produce is limited by the skin resistance of the produce. This in principle can result in a situation in which the internal partial pressures inside the produce can deviate from the conditions inside the package. The actual partial pressures where the respiration process is located will determine the rate constants of the respiration. Therefor the value of the skin resistance is of importance.

The university of Pisa is the only participant involved in this task. Pisa determines the skin resistance for the three produces and its temperature dependence. In this reporting period resistance to O_2 and CO_2 in the Golden Delicious has been measured at five different temperatures (21, 16, 11, 6 and 1 °C) utilizing for different gasmixtures. Thus the skin resistance of Golden Delicious O_2 and CO_2 at a function of the temperature has been determined in this project.

Task 3 Respiration as a function of ambient gas composition and temperature
The validity of the MASTER model is strongly determined by the validity of the submodel of respiration under modified atmosphere conditions. The systems oriented approach should result in a model structure valid for all the selected produces. The aim of this task is to collect a large data set under a wide range of partial pressures at the defined temperatures in order to have a large data set to validate the respiration model to be developed in task 4.

A respiration matrix consists of 4 oxygen partial pressures (0, 3, 10.1, 21.3 kPa) and 5 carbon dioxide partial pressures (0, 5, 10.1, 15.2, 20.3 kPa) which has to be measured for each products and temperatures shown for task 1 (i.e. 360 different main measurements) for the whole project period.

The status of this task is given in table 1 which shows for which product-temperature-gasconditons combinations the measurements have been performed. The goal of determining at least 140 different product-temperature-gasconditions combinations before the midterm assessment has been reached. With the finalisation of the three new respiration set-ups at INRA the initial delay will be made up arrears in the rest of the project.

The results of this task is a data set of respiration rate at various conditions. The format of the data set has been carefully defined so that data analyses of the respiration model (task 4) can be executed at ATO-DLO in the forthcoming periods of the project.

Table 1: Overview of the available respiration data.

		CHICORY					TOMATO					APPLE			
CO_2/O_2	°C	0	30	101	213	°C	0	30	101	213	°C	0	30	101	213
0	1				1	8					1	1	1	1	1
50												1		1	1
101												1	1	1	
152												1	1		
203												1	1		1
0	6				6	13		5	5	2	6	1	1	1	1
50			1	1	1			3				1		2	1
101			1	1	1				1			1	1	1	1
152		1	1	1	1					2		1	1	1	1
203		1			1								1	1	1
0	11		5	5	3	18		4	4	2	11	3	3		
50		4	4	1	1			4					3		
101		4	1	2	1				3					3	
152			3	4	3					3					3
203															2
0	16		15	12	17	23					16	1	7	10	4
50			3									1	3	1	1
101				3								1	1	5	1
152					1							1	1	1	3
203												1	1	1	5
0	21				14	28					21	5	1	1	12
50		1	1	1	1							1	1	1	1
101		1	3	3	1							1	1	1	1
152		1	3	3	1							1	2	1	
203		1	1	1	1							1	1	1	1

Task 4: Modelling of the respiration rate

The modelling of the respiration rate is based on the data gather in task 3. During the initialisation of the project the modelling of the respiration was focused on the structure of the description of the respiration and not on the validation. During this year the model repeatedly has been validated based on the growing data set for the three produces.

The temperature dependence of respiration rates are to be described by Arrhenius type equations, for alcoholic fermentation and for aerobic respiration.
For the dependence of respiration activities on gas partial pressures, the first results support the applicability of kinetic models for aerobic respiration, alcoholic fermentation and their inhibition by higher CO_2 partial pressures.

Task 5: Survey and selection of packaging materials.

Here, 9 different materials have been selected in the project:
- Polyethylene (PE) as abundant cheap material
- Polyvinylchloride (PVC) as reference material which is frequently in use but strongly under pressure
- Polypropylene, microperforated (P Plus), a material developed in co-operation with partner P2
- Polystyrene
- Ethylvinylacetate / Polyethylene - Copolymer (EVA/PE)
- Polyester / Polyether - Copolymer (known as Sympatex® for textile applications)
- Poly-ε-Caprolactone (PCL), a synthetic biodegradable material
- Cellulose acetate and
- Cellulose as biodegradable materials from renewable sources.

Task 6: Temperature dependent gas and water vapour permeability constants

The goal of this task is to collect packaging material specification to fill the database in task 8 and for the validation of the sub model on diffusion through packaging materials. This task is carried out by FhILV.

Here, a straightforward analysis of 3 materials per year was planned originally in the technical annex of the project.

The first project results show that this task has to be extended - and that the time frame has to be modified accordingly - due to the following reasons:

* Gas transport characteristics of all materials tested show a marked dependence on relative humidity in the gas atmosphere.
* Water vapour transport characteristics depend on temperature, and also not only on the relative humidity gradient across the film material (the driving force for permeation), but on the actual relative humidity on either side on the film, too
* Realistic conditions for MAP with relative humidities near 100 % inside the packaging and about 50 % outside differ largely from the normal conditions in gas permeation cells commercially available.

For the selected materials, values for O_2, N_2, CO_2 and H_2O transmission under standard conditions are given in table 2. Note that differences relative to the previous report are due to differences in nominal and real thicknesses of films and due to the selection of specific types of PE and PVC.
For the temperature behaviour of gas transmittance, Arrhenius-type approaches can be applied for all materials except for the microperforated P Plus, with formal activation energies between 19 KJ mol $^{-1}$ for PCL/CO_2 and 61 KJ mol^{-1} for EVA/PE/N_2. The water vapour transmittance mainly depends on the absolute water vapour concentration differences across the films and - to a lower extent - also on temperature. For this behaviour and for the combined humidity / gas transmittance behaviour, analytical expressions are still to be verified.

Table 2: overview on materials (for 100 μm film thickness, basis: 23 °C)

Material	CO_2 / O_2 permeability ratio	O_2-transmission (cm^3/m^2 d bar)	N_2-transmission (cm^3/m^2 d bar)	CO_2 -transmission	H_2O -transmission (g/m^2 d at 85 % → 0 % r.h)
PE	4.3	1170	303	5050	0.3
PVC	6.1	1030	277	6310	16
EVA/PE-Copolymer	4.0	1700	750	6800	1.7
Copolyether -ester	17.7	475	195	8430	282
Poly-(ε) caprolactone	7.6	2060	580	15640	106
Cellulose acetate ds 2.7	2.0	450	72	900	139
Cellulose	not known	0.5	below det. limit		131
Polystyrene	4.4	1470	333	6500	11.3
Polypropylene, micro-perforated (P⁺)*	4.4	some 1000 200000	some 1000 ... 200000	some 1000 ... 200000	0.7... 5 (calculated) 0.36 without pores

* not normelized to 100 μm thickness

Task 7: Modelling the diffusion process through the packaging material.
The diffusion model is one of the submodels of the MASTER model. The diffusion is described by Ficks law. The effect of the relative humidity on the transmission for O_2 and CO_2 for some of the materials under study have to be incorporated in the model. This indicates that sorption of the water in the packaging material has to be modelled and inter-linked with the gas transmission. The submodel has been designed for this functionality an will be further developed in the forthcoming periods.

Here, analytical expressions based on Arrhenius-type temperature dependence and linear approximations for relative humidity dependence of gas permeability's are already supported by the results of P4 for 7 respectively 2 materials.

Task 8: Building data bases
A small table with parameters of the packaging of some materials has been constructed, see table 3. Enlargements will be:
* The interlinked properties upon different humidities
* Water vapour permeabilities with their analytical expressions.

Table 3: Formal activation energies for permeation, E_a in kJ mol^{-1}, for the materials studied.

Material	O_2	CO_2	N_2
PE	49.15	45.65	58.16
PVC	44.16	35.81	49.56
EVA/PE	48.16	43.89	60.52
Copolyester-ester	49.86	35.33	59.03
PCL	31.95	18.74	32.71
Cellulose Acetate ds 2.7	28.10	33.22	31.06
Cellulose	most valuses below detection limit		
PS	26.60	24.70	35.00
Polypropylene microperforated	not applicable		

Task 9: Evaluation of the whole system for selected packages and products.
A suitable model structure has been set up, by ATO-DLO in the first year. A consistent description of the whole system is achieved by parameters related to ambient atmosphere, product characteristics, form of the package, film thickness & material and distribution situation. The model has been validated on MA packages with chicory experiments in this task.

MA packaging experiments at different temperatures on chicory have been performed by ATO-DLO and INRA. ATO-DLO has used the model packaging systems of which the parameters are scientifically well determined and INRA has used packages which are close to the packages which can be used commercially. It has been decided that chicory will be packed in) copolyester-ether copolymer ii) OPP (P-plus), iii)PVC and iv) PE. Typical results are depicted in figure 3.

Task 10: Maturity effects on the respiration rate
The maturity stage and the origin of the produce is very important for the respiration behaviour of the produce. It has therefor been recognized that the initial stage of the produce should be carefully determined for the three produce. The following characterisation for chicory has been decided: shape (chicory endives: closed shape required, given dimensional ranges. Changes in the O_2 consumption during storage have been found as illustrated in figure 4.

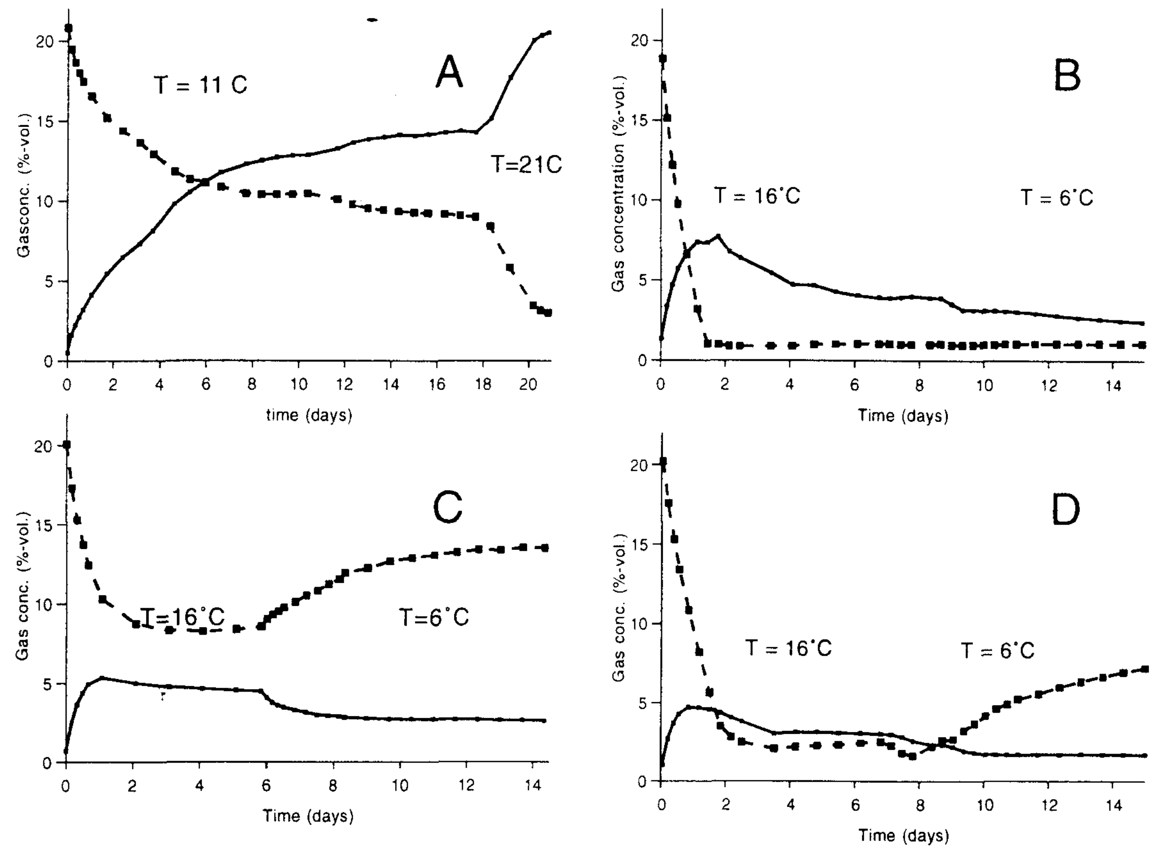


Figure 3: O_2 (drawn line) and CO_2 (dashed line) patterns in packages with chicory. (A) m=209gr, P^+, V=2l, A=620cm^2,T=11.21°C, (B) m=209gr, P^+, V=2l, A=620cm^2,T=11.21°C, (C) m=209gr, P^+, V=2l, A=620cm^2,T=11.21°C, (D) m=209gr, P^+, V=2l, A=620cm^2,T=11.21°C.

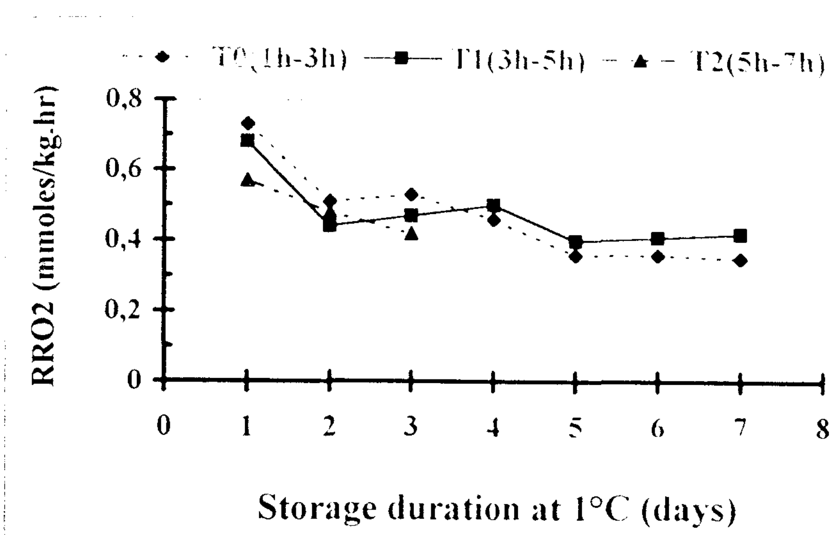


Figure 4: O_2 respiration rate of Witloof at 10°C as a function of assessment and storage durations.

Task 11: Project management

Project meetings are arranged at regular bases; they were held in Wageningen (February 1/2, 1994), Munich (June 20/21, 1994), Pisa (December 12,13), Montfavet (June 19/20, 1995) and in Leuven (October 9/10, 1995). Flow of materials and results had to be arranged according to the project necessities.

Chapter 4 : Discussion

The results obtained in each task are briefly discussed below. More detailed discussions are given in yearly progress report.

Task 1: Survey and selection of the agricultural produce.
The selection for apple, tomato and chicory has been made on economical and scientifcal bases.

Task 2: Gas transport in the product
The internal diffusion O_2 of for Golden Delicious apples has been measured at various temperatures by the university of Pisa. The gastransport can be described by the kinetic equation (Fick) with the constant k_i, and H.

$$R_m = d[O_2^*]/dt = R_{m,i} - R_{m,-i} = k_i/HA\,[O_2^*]_{eq} - [O_2^*])$$ <1>

These constants are independent of the presence of other gasses than the gas responsible for the driving force. The Henry constant H is independent of the temperature in the tested interval from 1 to 21 °C but the k_i shows a small temperature dependence according an Arrhenius dependence with an activation energy of 2.6 kcal/mol.

Task 3 *Respiration as a function of ambient gas composition and temperature*
The respiration rate for apples, chicory and tomatoes have been determined at various gasconcentrations and temperatures by University of Pisa, VBT and INRA. The respiration data have been analysed to validation of the temperature dependence, by each partner separately, confirms the Arrhenius dependence.
Analyses of all respiration gathered over all participants are discussed in task 4.

Task 4: Modelling of the respiration rate
The modelling of respiration will be based on aerobic respiration and anaerobic fermentation of which the temperature dependence can be described according a Michaelis Menten kinetics.

$$C_6H_{12}O_6 \xrightarrow{-2\,H_2} 2\;C_3H_4O_3 \;\begin{cases} \xrightarrow[+2\,H_2]{+6\,O_2} 6\,CO_2 + 6\,H_2O \\ \xrightarrow{+2\,H_2} 2\,C_2H_5OH + 2\,CO_2 \end{cases}$$

According to this scheme the overall hexose metabolization pathway was divided in two steps. The first step is connected with glycolysis and then with hexose conversion in two moles of pyruvate which, according to the second step, can be transformed to given CO2 and H2O (aerobic condition) or to produce ethanol and CO2 (anaerobic condition).

This assumption made at the start of the project seems to be supported by the currently gathered data in task 3. Statistical analysed give explained parts up to 85% on the available data for several product-temperature combinations. Lower explained parts (still more than 40%) can be attributed to too small data sets. This will be overcome in the future of this project when more data will be available.

Task 5: Survey and selection of packaging materials.
The selection of the packaging materials has been based on a general classification of perishable produces which require high, medium or low barrier materials for O_2 CO_2 and water vapour transmission.

Task 6: Temperature dependent gas and water vapour permeability constants
The permeation measurements demonstrate

* the good approximation possible for the pure temperature dependence by Arrhenius approaches,
* the main dependence of water vapour transmittance from the absolute water vapour concentration difference across the films,

but also that

* the interrelation of gas transmittance with humidity and
* the additional complex effects due to temperature and sorption characteristics of the materials have to be taken into account.

Literature data and supplier' s specifications have shown to be quite different from the real behaviour for the former two points and to be scarcely available for the latter two.

Task 7: Modelling the diffusion process through the packaging material.
The results obtained in task 6 confirm the Arrhenius-type temperature dependence and linear approximation for relative humidity dependence for 2 materials. This dependence is incorporated in the MASTER submodel for diffusion.

Task 8: Building data bases
Datasets of several films are available in the MASTER model.

Task 9: Evaluation of the whole system for selected packages and products.
The structure of the MASTER model has been designed and built in a 4^{th} generation computer language(PROSIM). It shows the desired functionality and flexibility required for the development of MASTER model.

The performance of the MASTER model has been analysed based on the packaging experiments with chicory. Due to the limited data on the packaging films, the model is only validated for the PE film under various assumptions such as the neglecting of the anaerobic respiration. The CO_2 give good correspondence between the calculated and the experimentally found values. For the O_2 a mismatch of 2% during the steady state can occur but this is acceptable for the various partners. These deviations will most likely decrease as the project will advance for more precise data on the product and the packaging material will become available.

Task 10: Maturity effects on the respiration rate
Effect of the maturity of chicory have been quantified for several temperatures. Adjustment in the MASTER model are planned in order to incorporated the effect of the maturity to some extend. Note however that it is out of the scope of this project to tackle the effects of maturity in detail.

Chapter 5: Dissemination

The following publications have been submitted by the project partners during the reporting period:

- Andrich et al.: Acta Horticulturae, 343, 163-164 (1994)
- Andrich et al.: Acta Horticulturae, 368, 374-381 (1994)
- Andrich et al. in: Developments in Food Science, Automatic control of food and biological processes, J.J. Bimbenet, E. Dumoulin and G. Trystram (eds.) Elsevier, Amsterdam, 1994, p. 281.
- Evelo R.G. and Boerrigter H.A.M., Integral approach for optimizing modified atmosphere packages for elstar apples: a combination of product and packaging constraints, Packaging technology and Science vol. 7, p.195 (1994).
- Evelo R.G. and Horst J., Modified Atmosphere packaging on tomato: controlling gas and humidity, 9th world conference on packaging IAPRI 4-6 September 1995 Brussels Belgium. Proceedings p 243.
- Evelo R.G., Modified Atmosphere Systems in varying TEmperature Regimes. Workshop "Reseach and Development Project in the field of Fruits and Vegetables". 21 September 1995 Murcia, Spain
- Tijskens L.M.M. and Evelo R.G., Modelling colour of tomatoes during postharvest storage. Postharvest. Biology and Technology 4 p 85 (1994).
- Evelo R.G., Boerrigter H.A.M. and van den Boogaard G.P.J.M., Optimizing modified atmosphere packaging of elstar apples. An application of a modified atmosphere model. COST94 meeting Post-Harvest treatment of fruits and vegetables. Current statur and future prospects. Oosterbeek. The Netherlands. (in press)
- Evelo R.G. and Horst J., Modified Atmosphere packaging on tomato: controlling gas and humidity, 9th world conference on packaging IAPRI 4-6 September 1995 Brussels Belgium. Proceedings p 243.
- Evelo R.G., Modified Atmosphere Systems in varying TEmperature Regimes. Workshop "Reseach and Development Project in the field of Fruits and Vegetables". 21 September 1995 Murcia, Spain
- M. Herregods; Storage of tomatoes. International Symposium on Postharvest Physiology, Pathology and Technologies for Horticultural Commodities; Agadir, Marroco, 16-22 January 1994.
- M. Herregods; C.A.-storage and quality of fruits and vegetables. E.C.-Cost 94 Workshop, Bled. Slovenia, 18-20 April 1994.
- M. Herregods; New developments on storage of fruits and vegetables. National Storage Symposium, Plovdiv, Bulgaria, 9-11 May 1994.
- M. Herregods; Variability in quality and maturity of apples at picking time. E.C.-Eurofru Workshop, Wilhelminadorp, Netherlands, 18-19 May 1994.
- M. Herregods; Storage of fruits and vegetables. Storage Symposium, Skierniewice, Poland, 14-15 Oktober 1994.
- M. Herregods; New developments on storage of fruits and vegetables. E.G.- Cost '94, Workshop, Oosterbeek, Netherlands, 19-20 Oktober 1994.
- M. Herregods; Storage of Fruits and Vegetables. Asean International Symposium in Postharvest Technology, Hanoi, Vietnam, 8-9 December 1994.
- M. Herregods : Preservation of quality and nutritional value by CA storage.
- Cost 94 - Commission of the European Communities. Proceedings of Workshop, April 22-23, 1993, Milan, Italy : 14-23.
- M. Herregods : Perspectivas del mantenimiento de la calidad de frutus y hortalizoes. Horticultura, Spain, Vol XIV, n° 6, sept 1995 : 27-33
- M. Herregods : Current research on postharvest handling of fruit and vegetable. Proceeding Workshop Postharvest Technology, Hanoi, Vietnam, 8-9 dec. 1994 : 27-30

- M. Herregods : Preservation of the quality and nutritional value of fruit and vegetables. Workshop pre- and postharvest factors and technology, Acta Horticulturae, 379, 1995 : 321-328
- Langowski, H.-C.: Barriereeigenschaften von beschichteten Packstoffen: Eine Ubersicht. To be published in Allgemeine Papier-Rundschau, Keppler-Verlag, Heusenstamm, 1995.