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Real world dynamic load test of a corrugated paperboard MA-box filled with Elstar apples

Evaluation of gas composition, quality effects and modelling

A progress report

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The work presented in this report is part of the KNP BT / ATO-DLO MA-project

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Summary

As a part of the KNP BT/ATO-DLO MA-project a new corrugated paperboard MA-box for "Elstar " apples has been tested under both static and "real world" dynamic conditions. The latter situation was achieved by putting a pallet stacked with MA-boxes filled with apples in a van. This van was driven two times during approximately 10 hours on various roads in The Netherlands.

Effects on gas conditions in the boxes and on quality aspects of the product were studied. For an integral approach in the process of optimizing an MA-box also other measurements were included in the experiments e.g. leakage rates of the boxes, respiration of the product and gas composition in the boxes.

The first point of study was whether the dynamic loads, as occur during practical transport, may be simulated by a vibration test system. Moreover, to what extent the standard test method (ASTM 4169 II) should be adapted to obtain a practically relevant test. It turns out that with 25% of the standard method ASTM 4169 level II on the vibration test system similar dynamic loads were obtained as occured during the practical transport.

After two and four weeks storage at 8°C the quality i.e. the firmness of the inspected apples in the MA-boxes was significantly higher than the firmness of standard packed apples. There was no difference between the static or the dynamic stack. Gas measurements showed that MA-conditions were not optimal. The major reason was that the tested box did not have the optimal dimensions to pack 12 kilos apples. Only 8 kilos could be packed in the boxes without damage risks. Hence, it is expected that the performance of a well adjusted box size will even be better than with this currently tested box. A secondary reason for rather low CO_2 levels was the relatively low respiration rate of the product. This was concluded from the respiration rate measurements with the examined product. Respiration data were collected during the experiments for parameterisation of product activity in the ATO-DLO MA-simulation model. All collected data were finally used to evaluate the model and for the prediction (including dynamic situations) of gas conditions in MA-boxes.

A general conclusion of all described tests is that transportation of MA-boxes does not negatively influence the improved functionality.

Content

1. Introduction

"Elstar" apple is the most important apple variety in The Netherlands from an economical point of view, though the keepability of this cultivar especially at higher temperatures is rather limited. The main reason is that "Elstar" apples are highly sensitive to early softening. In general the shelf life is restricted to 1 week; after this period apples become too soft and mealy to consume. Earlier work of ATO-DLO showed that with specific Modified Atmosphere (MA) conditions firmness of "Elstar" apple was much better retained compared with non MA-packed apples [ref. 1 en 2]. The optimal and safe MA-conditions in relation with firmness retention appeared to be: 5% oxygen (O_2) and 8-10% carbon dioxide (CO_2). Other ATO experiments with "bag in box" MA-packages for 12 kg apples demonstrated that ripe picked "Elstar" could be stored up to three months at 1.5°C and retained firmness much better than apples packed in standard boxes.
Based on these results the KNP-BT and ATO-DLO MA-project team decided to develop a MA-box for apples as a part of the MA-project.

This report describes three experiments and one model. In the first experiment the leakage of a new corrugated paperboard MA-box under both static and dynamic conditions was measured. In the second experiment respiration of the apples under different gas conditions was measured. In the third experiment the efficiency and the MA-advantage of the product-box combination was tested by means of quality inspections of the MA-packed apples.This third test was not only carried out at stationary conditions but the effects of a "real world" dynamic load on the packages and the apples were also included. The dynamic load was achieved by putting a pallet stack with boxes in a van. During two periods of about ten hours the van was driven across The Netherlands on several roadtypes. In order to evaluate the ATO-DLO MA-simulation model for "Elstar" apples the results of the respiration measurements were put in the database. Based on that some MA-model simulations were performed.

2. Goals of the experiments

The primary goal of the experiments was to study the MA advantage of a new corrugated paperboard MA-box for "Elstar" apples.
A secondary goal was to study how realistic dynamic load conditions could be simulated on a vibration test system and to what extent this dynamic situation effects the apple quality.
The third goal of the experiment was to evaluate the ATO-DLO MA-model for a paperboard MA-box for "Elstar" apple.

3. Material and methods

3.1 Product

"Elstar" apples from one grower were obtained at a Dutch auction (RWM-Ochten) on 26 March 1997. After picking the apples in September 1996 they were stored in a CA-storage room (1.5°C and 3% CO_2-1.2%O_2) for 25 weeks. Within two days after CA-storage the apples were sorted, inspected for quality and moved to ATO. The initial firmness at the start of the experiments was 6.4 kg/cm^2. Quality classification was: Super Class I and the radial size of the apples was between 70-75 mm.

3.2 Product quality measurements

After regular periods in time a visual quality inspection of the apples was carried out on both internal and external deficits like: rot, fungal growth, skin injuries, internal discolouration, etc.. To detect possible fermentation (i.e. off-flavors) samples were tasted and off-odors were detected at the moment of opening the MA-boxes. Firmness was measured instrumentally by using an Effe-gi fruit penetrometer. A plunge with a diameter of 1 cm. was used. Weight loss of the apples was measured after 2 and 4 weeks using a mass balance. In every MA test-box gas concentrations were determined 8 times per day during the whole test period of 28 days. For gas analysis a Chrompack gaschromatograph CP2002 provided with an automatic sampling and calibration system was used.

3.3 Packages

In the experiments a corrugated paperboard box was tested. By adapting the construction and using special paperboard qualities, the MA-box was designed. Points of interest were the used coating, minimizing leakage through construction, only cutting edges. The used paperboard quality was: 205 gr SWL (15 gr LDPE) on both sides).The box is closed with three pieces of plastic tape. Box properties and the calculated permeance are given in Table 1. The used box is depicted in figure 1.

Table 1: Box properties and the calculated permeance.

Property	value
Box height (inside) [m]	0.12
Box width (inside) [m]	0.59
Box length (inside) [m]	0.36
Volume [l]	25.5
Permeance wall [ml/(m^2.min.Bar)]	23.5
Box wall area [m^2]	0.65
Permeance box through material [ml/(min.Bar)]	15.3

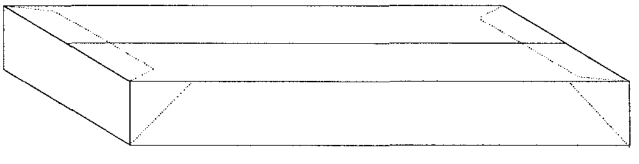


Fig. 1: Design of used box.

As a reference standard package for the corrugated paperboard box a blue coloured EPS plastic crate with the internal dimensions: length x width x height= 0.566m x 0.366m x 0.169m was used in the experiments.
Both package types were combined in one pallet stack. Two pallets were made. One stack was used for the dynamic load treatment, while the second was not moved at all during the experiment (static test).

3.4 Pallet stack

The bottom layer of the pallet stack was a dummy layer (paperboard boxes filled with artificial lemons). The second layer contained boxes with lemons for measuring the box permeance. The third layer consisted of boxes filled with apples as a dummy layer. The fourth and fifth layer contained boxes filled with apples used for the quality measurements. These layers were covered with a layer containing boxes with apples as a dummy load. On top of these six layers two layers with EPS plastic crates filled with apples were placed. The top layer consisted of empty plastic crates. The stack used for testing at static conditions was equal besides that it did not contain layers with boxes filled with artificial lemons. Every layer contained 5 packages. Earlier experiments showed that dynamic effects occur especially at the upper part of the pallet. Therefore we restricted ourselves by testing only half a pallet. Figure 2 shows an overview of the pallet-stack used in the experiments.

Fig. 2: Pallet stack scheme during MA-box test

EPS-empty	dummy package	layer 9
EPS-apple	quality test 2	layer 8
EPS-apple	quality test 1	layer 7
MA-box apple	dummy load	layer 6
MA-box apple	quality test 2	layer 5
MA-box apple	quality test 1	layer 4
MA-box apple	dummy load	layer 3
MA-box lemons	leakage test	layer 2
MA-box lemons	dummy load	layer 1
Pallet		

3.5 Temperature-time conditions

The storage temperature of the packages filled with apples was 8°C. The apples were stored during 4 weeks. After 2 and 4 weeks a quality inspection of the product was executed. In order to investigate the effects on shelf life of the package type, product samples were placed on the shelf. The conditions were 20°C/60%RH. After being stored during 4 and 7 days in these conditions, the apples were inspected and measured again on all relevant quality aspects. Temperature conditions during the box permeance measurements and the dynamic load test varied depending on the location where the tests were carried out (see chapter 3.6).

3.6 Gas transmission rate of MA-boxes

Five boxes were tested under different dynamic conditions. Each dynamic experiment was alternated by measurements under static conditions. Dynamic tests were performed on a vibration test system at Shape technology and under realistic transport conditions in a van. In order to simulate a product load, the boxes were filled with 9 kg of artificial lemons. To facilitate the measurements for determination of the gas transmission rate, two tubes were connected to each box. At the beginning of each experiment, before closing or connecting the tubes, three liters of carbon dioxide (CO_2) have been injected into each box. Then one tube was closed and the other was connected to a Chrompack gaschromatograph. Every 30 minutes 3 ml. samples of gas have been taken out of each box. By analysing the composition of each sample, the gas concentrations have been obtained as a function of time. From these data the gas transmission rate of a box could be determined through:

$$F_{box} = -\frac{d}{dt} \cdot \ln(p_{a,ins}(t) - p_{a,out}) \cdot V \qquad (1)$$

where t is the time in [min], V is the volume of air inside the box , i.e.

$$V = V_{box} - N_{lem} \cdot V_{lem} \qquad 2$$

N_{lem} is the number of lemons in the box and V_{lem} the volume of one lemon. This volume is taken constant for every lemon (V_{lem} = 85 ml) while the number of lemons is counted for every individual box.

Gas exchange in MA-boxes is distinguished in diffusion through the packaging material (P.A) and the gas flow through leaks in the construction (L_{box}). Since these processes are independent from each other, the total gas flow may be described by (for details see [ref. 3])

$$F_{box} = L_{box} + P.A \qquad (3)$$

F_{box} is defined as the total gas transmission rate out of or into a box in [ml/(min.bar)], L_{box} is defined as the leakage of a box in [ml/(min.bar)], P is the permeance of the paperboard box in [ml/(m^2.min.bar)]and A the area of the box in [m^2]. The gas transmission rate F_{box} can be computed from the slope of the natural logarithm of the partial gas pressure inside the box plotted versus the time. The value obtained this way gives a total gas flux. To separate the contribution of leakage and diffusion it is necessary to measure the permeance P of the box material separately. In these experiments only the overall value F_{box} was measured.

Because the boxes were produced, filled and connected to tubes manually, a qualitative check was performed at ATO-DLO in experiment one (*stat1*). This experiment is repeated in order to investigate the initial leakage of the boxes under the experimental conditions at Shape Technology (*stat2*). Subsequently the box transmission rate was measured under dynamic conditions with an intensity of 25 % of ASTM 4169 Level II (0.25 ASTM II). In order to investigate permanent damage to the boxes, box transmission rates under static conditions were measured again (*stat3*). In the fifth experiment the intensity of the dynamic excitation was increased to 50 % of ASTM 4169 Level II (0.5 ASTM II) and again the occurrence of permanent damage was investigated (*stat4*). A few weeks later boxes were put in a pallet and driven through the Netherlands in a van for about 10 hours and 500 kilometres (*van1*). Again permanent damage was tested (*stat5*). These two tests were repeated two weeks afterwards (*van2, stat6*). Temperatures, relative humidities and duration of the separate experiments are given in table 3.

Table 3: Conditions during box transmission tests in subsequent order.

No.	Name	Location	Dynamic conditions	T (°C)	RH (%)	Time (min)
1	stat1	ATO-DLO	Static	18	75	1100
2	stat2	Shape	Static	16	60	200
3	0.25ASTMII	Shape	25% of ASTM4169 II	17	60	160
4	stat3	Shape	Static	20	60	700
5	0.5ASTMII	Shape	50% of ASTM4169 II	18	60	200
6	stat4	Shape	Static	18	60	160
7	van1	Van	Driving	10	70	600
8	stat5	ATO-DLO	Static	8	95	200
9	van2	Van	Driving	10	75	600
10	stat6	ATO-DLO	Static	8	85	200

For the dynamic load a percentage of 25 % and 50 % of transport simulation ASTM 4169 level II is chosen. This assurance level corresponds to the vibrations occurring during transport in a truck with air suspension. For details about the ASTM levels and the experimental conditions at Shape Technology see [ref. 4].

3.7 Respiration and modelling gas exchange

The respiration rate of "Elstar" apples was measured at several gas conditions. Measured values were used for fitting gas exchange models. The obtained models were used to predict gas conditions inside MA packages. For gas exchange measurements, apples (*Malus domestica* cv. "Elstar") were placed in 1.5 l flasks (two apples per flask). Temperature during the experiments was 8°C. Combinations of oxygen and carbon dioxide were applied using a flow through system. Per gas condition two flasks were used. Gas conditions are shown in Table 4. The flow rate was 400 $ml.min^{-1}$. The gas coming into a flask was humidified by leading the gas through a 500 ml water flask. The relative humidity was > 95%. Gas exchange rates were measured after 3, 5, 7, 10, 14, 17 and 21 days of storage.
To calculate gas exchange rates, the flasks were closed and placed in another room (8 °C) where O_2 and CO_2 concentrations were measured using a Chrompack CP 2002 gas-chromatograph. After 4 hours a second measurement followed. Gas exchange rates were calculated using the

change in gas concentrations, the free volume of the flasks, the exact time period between the two measurements, and the fresh weight of the apples. After the second measurement, flasks were connected to the flow through system again.

Table 4: Combinations of O_2 and CO_2-concentrations (%-vol.) used

O_2 (%)	CO_2(%)
0, 0.5, 5	0, 5, 10
17	5
21	0, 10

Modelling gas exchange

The experimental data on gas exchange rates were used for fitting an O_2 consumption and a CO_2 production model. For O_2 consumption, and the CO_2 influence on O_2 consumption, a model with noncompetitive type of inhibition by CO_2 was used [ref 5]:

$$V_{O_2}=\frac{Vm_{O_2}\cdot O_2}{(O_2+Km_{O_2})\cdot(1+\frac{CO_2}{Kmn_{CO_2}})}$$

where V_{O2} is the actual O_2 consumption rate (ml.kg^{-1}.h^{-1}), Vm_{O2} is the maximum O_2 consumption rate (ml.kg^{-1}.h^{-1}), Km_{O2} is the Michaelis constant for the inhibition of O_2 consumption by O_2 (% O_2), and Kmn_{CO2} is the Michaelis constant for the noncompetitive inhibition of O_2 consumption by CO_2 (%CO_2).

For CO_2 production, and the CO_2 influence on CO_2 production, a model with inhibition of both oxidative and fermentative CO_2 production by CO_2 was used:

$$V_{CO_2}=V_{O_2}\cdot RQ_{ox}+\frac{Vmf_{CO_2}}{1+\frac{O_2}{Kmf_{O_2}}+\frac{CO_2}{Kmf_{CO_2}}}$$

Where V_{CO2} is the actual CO_2 production rate ($ml.kg^{-1}.h^{-1}$), RQ_{ox} is the ratio between oxidative CO_2 production and O_2 consumption, Vmf_{CO2} is the maximum fermentative CO_2 production rate ($ml.kg^{-1}.h^{-1}$), Kmf_{O2} is the Michaelis constant for the inhibition of fermentative CO_2 production by O_2, and Kmf_{CO2} is the Michaelis constant for the inhibition of fermentative CO_2 production by CO_2.

3.8 MA-simulation model

The respiration rates of the apples are integrated in the MA simulation model [ref.5] by using the gas exchange models obtained as described in chapter 3.7. In this simulation model product processes (gas exchange), material properties (diffusion) and temperature effects are incorporated in one advanced simulation tool. Calculations have been made to compare calculated and measured values of gas composition in the corrugated paperboard MA-box.

3.9 Statistics

All treatments consisted of 5 replicates per treatment. In order to determine the significance of differences of input variations an analysis of variance (ANOVA) was carried out using the statistical package "Genstat". The significance level was put to 95%.

4. Results

4.1 Leakage tests

The box transmission rates for all conditions are given in table 5.

Table 5: Measured box transmission rates (ml/min)

no.	stat1	stat2	0.25 ASTM	stat3	0.5 ASTM	stat4	van1	stat5	van2	stat6
1	12.6	12.4	28.7	12.3	95.6	12.8	14.9	12.1	24.1	11.6
2	8.4	8.8	10.4	8.8	12.3	9.1	14.6	11.8	23.4	11.6
3	9.1	8.6	8.8	8.4	10.0	8.5	21.9	12.2	26.2	11.8
4	12.1	11.7	59.9	11.9	193.1	13.4	16.5	11.1	47.4	13
5	*	19.5	21.5	18.7	31.8	19.3	79.3	16.2	21.5	11.3
avg	**10.6**	**12.2**	**25.9**	**12.0**	**68.5**	**12.6**	**29.4**	**12.7**	**28.5**	**11.9**
std	1.8	3.9	18.5	3.7	69.6	3.9	25.1	1.8	9.6	0.58

* This experiment was corrupted.
Equation (1) fitted very well to the measured values as the R^2 in all measurements was close to one (value=0.9999).

An analysis of variance (ANOVA) with these data showed that:

- The gas transmission rates under static conditions do not differ significantly.
- Under dynamic circumstances, gas transmission rates show high standard deviations.
- Transmission rates under a dynamic load of 50% of ASTM level II are significantly higher than the transmission rates under other tested dynamic conditions.
- There was no permanent damage due to vibrations.

4.1.1 Conclusions leakage experiments

- Dynamic loading does not cause permanent damage to the tested corrugated paperboard MA-boxes.
- Gas transmission rates under realistic dynamic conditions in a van may be simulated by 25% of ASTM level II.

4.2 Respiration

Statistical comparison of actual O_2 uptake rate with the used gas models (see section 3.7), showed high percentages of explained variance (R^2) (Table 6). This indicates that this model gives a good description for the O_2 uptake rate.
The Vm_{O2} values (maximum O_2 uptake rate) and Km_{O2} values (O_2 concentration where the O_2 uptake rate is half of the maximum rate) indicated a quite constant O_2 uptake rate during the storage period. Especially at low O_2 concentrations, O_2 uptake rates were inhibited (Fig. 2 of the appendix). During the first 10 days in storage, CO_2 concentrations showed no or little influence on O_2 uptake rate. During the subsequent days in storage (day 14-21), elevated CO_2 inhibited respiration. The inhibition by CO_2 increased with storage period, as indicated by decreased Kmn_{CO2} values.

Table 6: Regression analysis of O_2 consumption data of "Elstar" apples

	Storage time (days) at 8°C													
	3		5		7		10		14		17		21	
	est	se	est	se	est	se	est	se	est	se	est	se	est	se
R^2	95.1		94.2		93.4		92.6		96.3		97.1		95.4	
VmO_2	4.4	0.2	4.2		3.8	0.2	3.3	0.2	4.1	0.2	3.9	0.2	4.3	0.2
KmO_2	2.4	0.4	2.3		1.6	0.3	1.3	0.3	2.3	0.3	1.9	0.3	2.4	0.4
$KmnCO_2$	*		*		673	2757	*		174	170	85.6	39.7	36.4	10.5

R^2= % variance accounted for
*= very high values for $KmnCO_2$ (no inhibition by CO_2)
est= estimated se= standard error

The fitted CO_2 production model resulted in good values for R^2 (Table 7). The CO_2 production decreased when O_2 concentration was lowered from 21% to ± 1% (Fig. 2 of the appendix). An increase of CO_2 production at O_2 concentrations close to 0 indicates fermentative CO_2 production. The maximum fermentative CO_2 production rate (Vmf_{CO2}, CO_2 production rate at 0% O_2) ranged between 5.3 and 7.9 $ml.kg^{-1}.h^{-1}$ during the storage period. The Kmf_{O2} values found, are indicating that the fermentative CO_2 production reached 50% of its maximum rate at an O_2 concentration around 0.1 %.
The CO_2 influence on fermentative CO_2 production is not large, as indicated by Kmf_{CO2} values. More important is the CO_2 influence on oxidative CO_2 production which is accounted for by the term V_{O2} * RQ_{ox} in the model. As with O_2 uptake, the CO_2 production is inhibited by elevated CO_2 after prolonged storage (14-21 days).
The RQ_{ox} values found, were lower than expected from other available data.[ref. 5]. Peppelenbos found RQ_{ox} values of 0.98 and 0.99 for respectively Elstar and Golden Delicious apples. Maybe,

in the current experiment, the measured CO_2 production was lower than the real CO_2 production. Untill now a scientific explanation for the difference is unknown.

Table 7: Regression analysis of O_2 consumption data of "Elstar" apples

	Storage time (days) at 8°C													
	3		5		7		10		14		17		21	
	est	se	est	se	est	se	est	se	est	se	est	se	est	se
R^2	79.1		86.6		68.7		78.6		85.0		90.9		89.9	
RQox	0.80	0	0.77	0	0.75	0.1	0.88	0.1	0.72	0.1	0.84	0	0.88	0
$VmfCO_2$	7.9	2.8	5.3	0.7	5.3	0.8	6.1	1.0	6.5	0.6	6.3	0.7	5.7	0.8
$KmfO_2$	0.0	0	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1
$KmfCO_2$	18.1	6.1	20.3	6.5	19.9	9.7	25.9	13.6	23.3	10.7	29.3	10.7	23.0	8.1

R^2 = % variance accounted for
est = estimated values
se = standard error

4.2.1 Conclusions respiration measurements

- Both decreased oxygen and elevated carbon dioxide concentration inhibit the respiration rate of "Elstar" apples.
- The applied models (especially the oxygen uptake) fit very well with the measured values ergo prediction of gaseous levels in MA-boxes is possible.
- The RQox value is lower than in other experiments was found.

4.3 Packaging experiment: Product quality and gas measurements.

Firmness

All inspected apples at any time did not show any visual injury (both internally as externally). Furthermore no off-flavors or off-odors could be detected. The only varying and most important quality factor: firmness showed significant differences between treatments. Table 8 shows the results of the firmness measurements. The measurements have been carried out at the moment the boxes were opened.

Table 8: Firmness (kg/cm²) of "Elstar" apples in different package types under static and "real world" dynamic load conditions and stored at 8°C.				
Packaging type	2 weeks		4 weeks	
	static	dynamic	static	dynamic
EPS-crate	5.1a	5.0a	4.7c	4.7c
MA-box	5.5b	5.4b	5.7d	5.8d

LSD value is 0.18 ($P<0.05$). Average values with the same letter do not differ significant.

As can be derived from table 8:
- The firmness of "Elstar" apples in corrugated MA-boxes is significantly better compared to a standard package (EPS crate). This is valid after 2 weeks as well as after 4 weeks of storage at 8°C.
- There is no effect on firmness from the dynamic load conditions.

Shelf life and firmness
The result of the shelf life tests regarding firmness was that there were no differences between load conditions (static or dynamic: data not shown). Table 9 indicate how firmness decreases when apples are stored at 20°C and 60%RH (shelf conditions).

Table 9: Effect of shelf life conditions (20°C) on the firmness (kg/cm²) of Elstar apples						
Packaging type	2 weeks			4 weeks		
	0 days	4 days	7 days	0 days	4 days	7 days
EPS-crate	5.1b	4.7d	4.2e	4.7y	4.3z	*
MA-box	5.5a	5.3ab	4.9cd	5.7x	4.7y	*

LSD value is 0.22 ($P<0.05$). In the anova storage time is analysed separately. * At this moment all apples were equal and too soft for adequate measurements.

- The positive effect of storing apples in MA-boxes is still present after 4 and 7 days shelf life. After 4 weeks storage and 7 days shelf life the differences are leveled.

- Softening of "Elstar" apples at higher temperatures happens very fast.

Weight losses
During the in-package storage time weight losses are determined. Table 10 gives the results.

Tabel 10: Effect of package type on weightlosses (%) of "Elstar" apples

Packaging type	storage time	
	2 weeks	4 weeks
EPS-crate	1.22b	2.62c
MA-box	0.66a	1.00ab

LSD= 0.34 (P<0.05). Average values with the same letter do not differ significantly.

- The MA-box prevents the product effectively for dehydration. Product in an open EPS-crate looses about twice as much as when packed in a MA-box.

- The product has lost more weight in 2 weeks EPS-crate than after 4 weeks being stored in a MA-box.

Gas conditions in MA-boxes
The elevated CO_2-concentrations and lowered O_2-concentrations were measured 8 times per day in all test boxes. To facilitate the presentation of the results the average value of the gas concentration on day 10 and day 26 are given in table 11.

Table 11: Gas concentrations in MA-boxes filled with "Elstar" apples under dynamic and static load conditions.

Package type	storage time			
	O_2(%-vol.)		CO_2 (%-vol.)	
	2 weeks	4 weeks	2 weeks	4 weeks
ma-box dyn	17.7a	17.6a	4.7y	4.7y
ma-box stat	18.5c	18.1b	4.0x	4.6y
EPS crate	20.7d	20.7d	0.035z	0.035z

LSD = 0.37 for CO_2 and 0.31 for O_2 (P<0.05). Values with the same letter do not differ significantly. Oxygen and carbon dioxide are treated as separated variates in the ANOVA.

- MA-conditions in stationary "dynamic load" MA-boxes are surprisingly more rigid than in the static load boxes. An explanation might be that two static test boxes out of 10 showed a different behaviour (leakage very high) possibly caused by the manual production of the boxes.

- During 4 weeks gas concentrations were quite stable in all test boxes.

- The box design is not fully appropriate for optimal MA-packaging as the desired gas concentrations were 8-10% CO_2 and 5-10% O_2 (earlier ATO-results). The major cause for not achieving the optimal gas conditions were the non-optimal box dimensions. Only 1 layer (about 8 kilos) could be packed in the boxes instead of the planned 12 kilos.

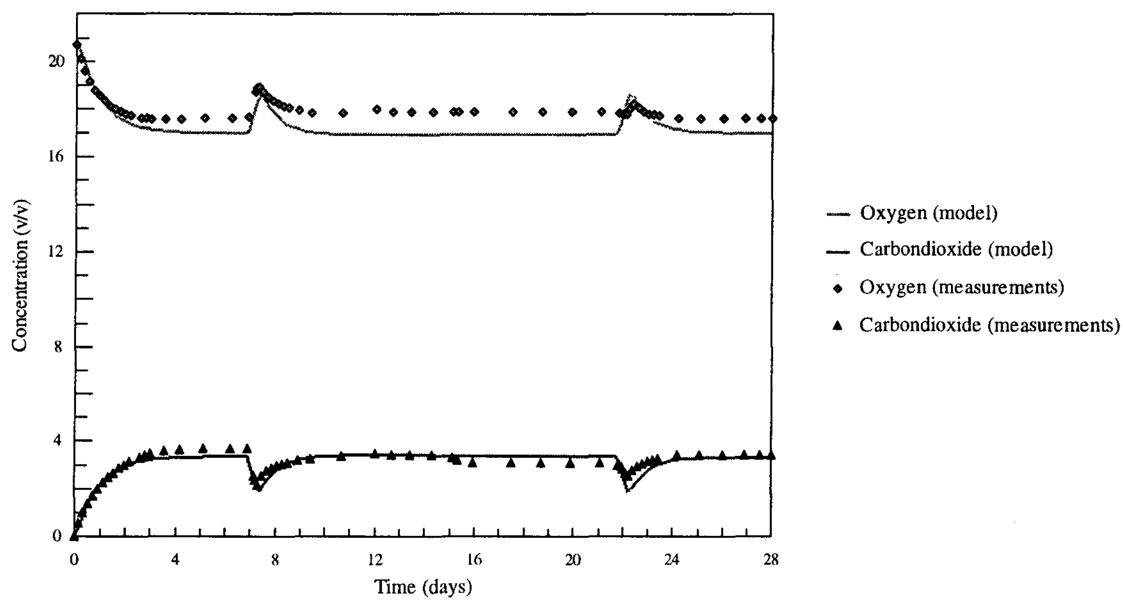
4.3.1 Conclusions packaging experiment

- Application of the tested corrugated MA-box will keep the product quality on a higher level during distribution as compared to the standard package.
- The design of the box should be optimized for packing "Elstar" apples.
- Dynamic loads did not influence product quality.

4.4 MA-simulation model

The MA-simulation model [ref. 5] has been used to investigate whether it was possible to simulate the effects of dynamic circumstances.
The result is shown in figure 3 and demonstrates to what extent the upgraded model for "Elstar" apples is capable to predict the gas levels in a MA-box (including "van" transport).

Figure 3: Comparison of calculated and measured gas concentrations in a corrugated paperboard MA-box filled with 8 kg Elstar at 8°C.



The calculated and the measured gas concentration are quite similar. Only the O_2-concentrations show a slight deficit. The measured values are approximately 1% higher as the calculated values.

- During transportation the leakage rates of the MA-boxes enhanced, resulting in a temporary change of the initial gas concentration. After stopping the transport i.e. the vibrations the same equilibrium was re-established in only a few hours.

4.4.1 Conclusions MA-simulation model

- There is no permanent damage of the MA-boxes after being excitated.
- The MA-model can be used for optimizing a MA-box for "Elstar" apples including the effects of practical dynamic load conditions.

5. General conclusions

- To simulate a "real world" dynamic load using a vibration table only 25% of the assurance level of ASTM 4169 II should be applied.
- The MA-box concept is valid for "Elstar" apple. Quality i.e. firmness is maintained on a higher level as compared to standard packaging.
- The MA-simulation model is valid for "Elstar" apple and also for calculating the effects of dynamic loads on consequences for gaseous levels inside MA-boxes.
- The test box was not designed optimally.

6. References

1) Boerrigter, H.A.M. (1995). Folie houdt Elstar stevig. Groenten+Hard- en zacht fruit/ Nederland-week 40-6 oktober: 4-5.
2) Boerrigter, H.A.M. (1996) Rijpe Elstar langer stevig door MA-bewaring. De Fruitteelt 28: 8-9.
3) Willems C., A. Berkenbosch and S. Stappers: Technical aspects of MA boxes; a progress report. ATO-DLO report B217, August 1996.
4) Weert van C.L.M., G.J.P.M. van den Boogaard: Dynamic testing of MA boxes II; A progress report, March 1997.
5) Peppelenbos, H. W. And J. Van 't Leven (1996): Evaluation of four types of inhibition for modelling the influence of carbon dioxide on oxygen consumption of fruits and ve getables. Postharvest Biology and Technology 7: 27-40.

6. Appendix: Measured values for Oxygen and Carbondioxide uptake

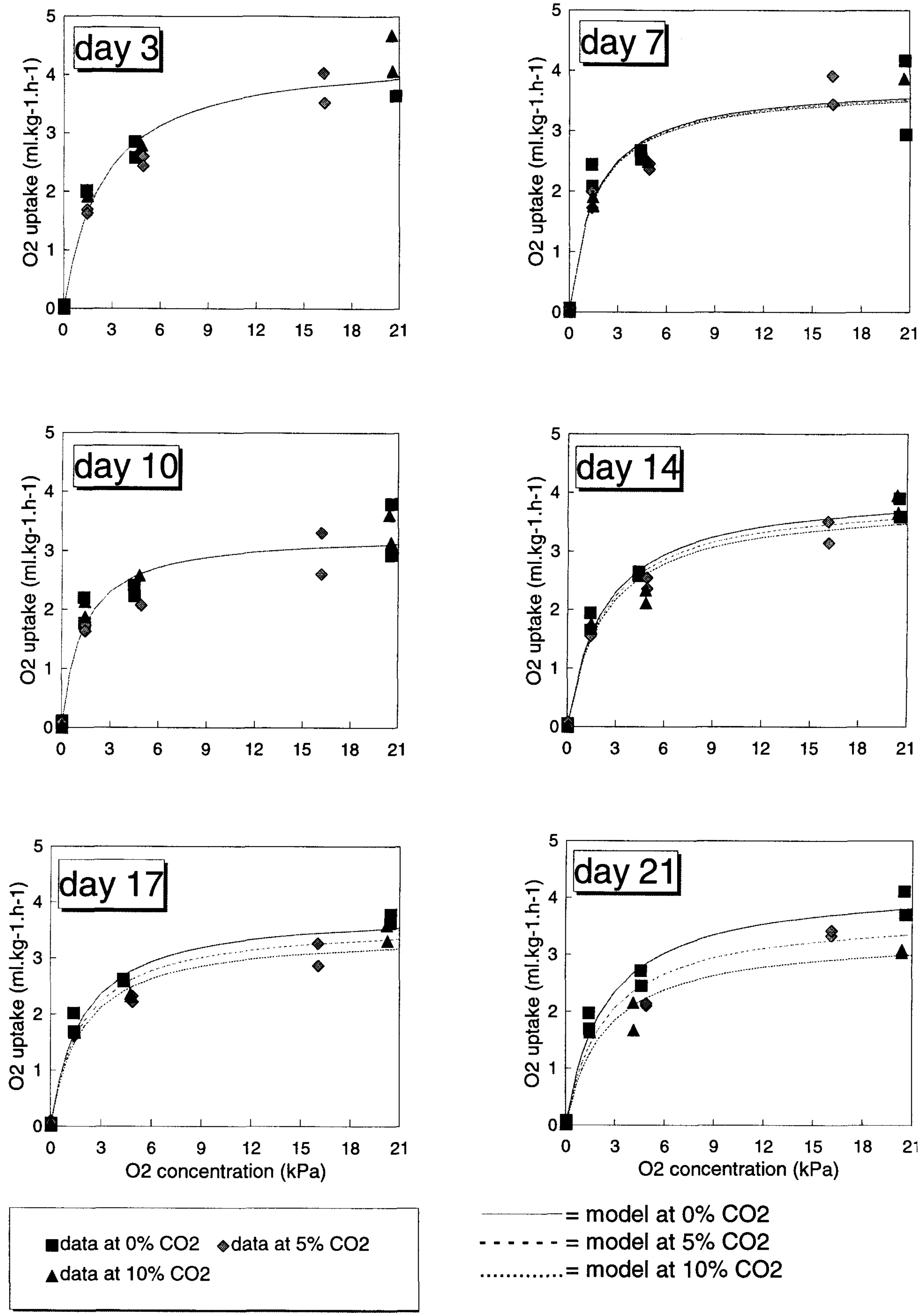


Figure 1. Measured values for oxygen uptake (ml.kg-1.h-1) at several days in storage and at several gas conditions, and fitted models for oxygen uptake.

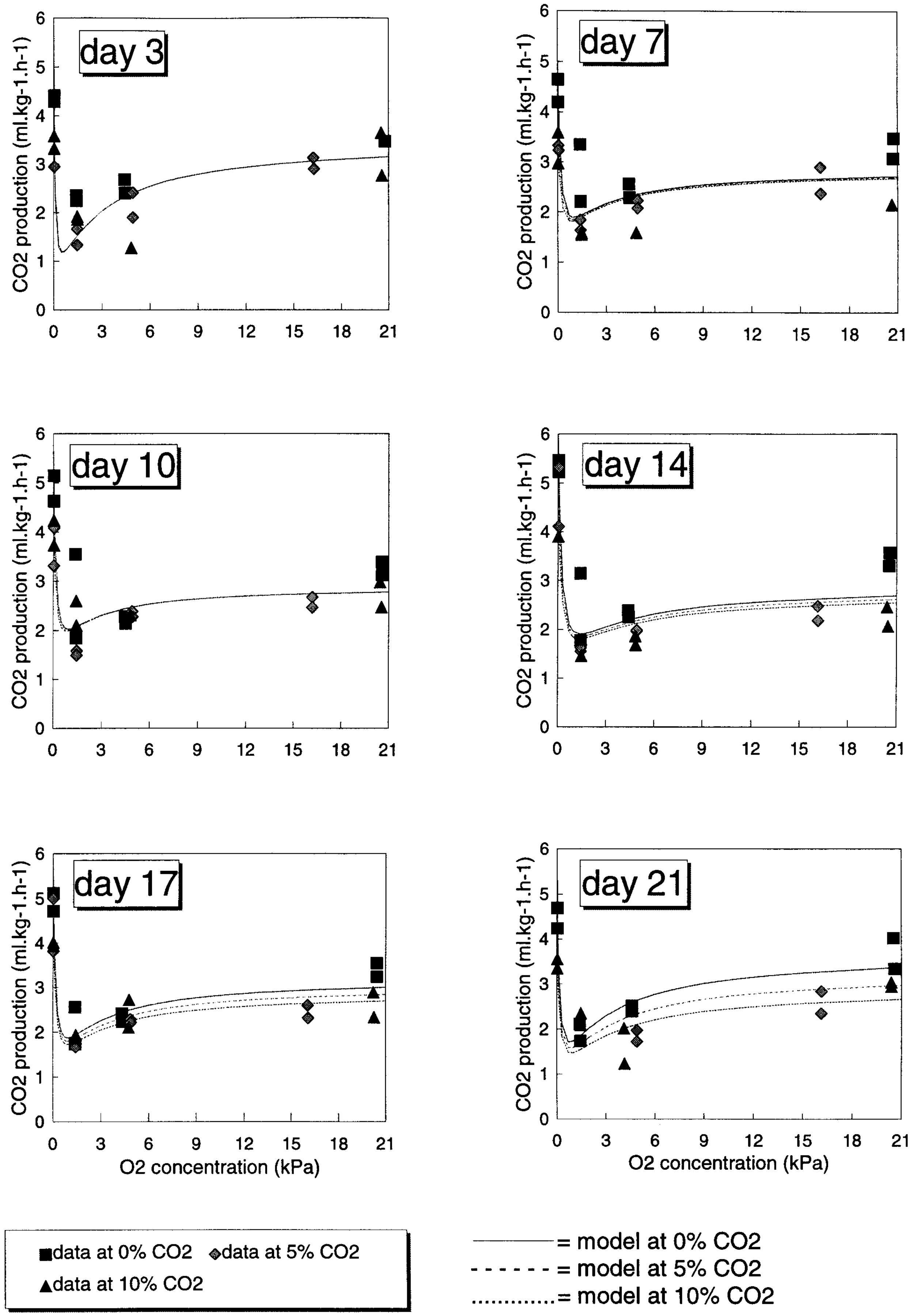


Figure 2. Measured values for carbon dioxide production (ml.kg-1.h-1) at several days in storage and at several gas conditions, and fitted models for carbon dioxide production.