ATO

A feasibility study on the use of Apack / AVEBE topseal trays for packaging of meat products

Confidential

Report B512 / July 2001

Ir. F.M.S. Martin
Ir. F.I.N.G. Kreft
Ir. J.G.J. Hermans
Dr. C.R. Jaeger

WAGENINGEN UR

A feasibility study on the use of Apack / AVEBE topseal trays for packaging of meat products

Confidential

July 2001

Ir. F.M.S. Martins
Ir. F.I.N.G. Kreft
Ir. J.G.J Hermans
Dr. C.R. Jaeger

Agrotechnological Research Institute
(ATO)
Bornsesteeg 59
P.O. Box 17
NL-6700 AA Wageningen
Phone: +31.317.475000
Fax: +31.317.475347

Confidential project report written by ATO for AVEBE and Apack

2251509

0 Management summary

Packaging trials with Apack trays which were coated and sealed with AVEBE Paragon laminate films were carried out with two types of meat products, chicken breasts and ground beef. Aim of the study was to gain insight into the shelf life of the packed product and to quantify the effect of the different material properties of the Apack / AVEBE system on the spoilage of the product.
In general, the Apack / AVEBE trays could maintain the protective atmosphere inside the packaging during several days. The packaging trials showed that the higher permeability of the Apack / AVEBE packaging leads in comparison with a standard PET package to a shorter 'sensory' shelf life (i.e. the shelf life based on sensory criteria like odour and colour which the consumer uses).

Evaluation	Shelf life chicken breasts, 5°C			Shelf life ground beef, 5°C	
	PET cel.	706 cel.	706 abs.	PET	661 cel.
Odour	21	10	14	7	7
Discoloration	>21	21	21	10	3
Microbial quality	14	10	10	2	2

The standard PET package looked much less advantageous, if a microbiological analysis is included into the evaluation: for the Apack / AVEBE packages; the end of the sensory shelf life coincided more or less with the end of the microbiological shelf life, whereas for the standard PET packages the sensory impression of the product was still acceptable when the microbiological state of the product was unacceptable.
The shelf life can potentially be increased by choosing different (non-standard) initial gas concentrations, laminates with improved barriers, or other techniques which slow down microbial growth. In addition, some end users might accept a shorter shelf life in return for a bio-degradable packaging.
An additional important observation was that the Apack trays absorbed moisture and became soft under the typical conditions of cold storage (90% RH). The moisture uptake weakened the mechanical strength of the trays which led (in combination with a low pressure inside the packaging caused by absorption and permeation of CO_2) to the collapse and leakage of several packages.

Contents

1 Background

Despite the efforts of the government, industry, and consumers to reduce the amount of packaging material in the waste stream, the amount of plastics in the waste stream is still increasing. In the Netherlands, 35% of the plastics production is used as packaging material. In addition to the significant growth of the plastics production (from 1.9 Mt in 1994 to 2.7 Mt in 1999), the amount of plastics entering the waste stream is also still growing (from 10.5 kt in 1994 to 13.7 kt in 1999).
The increase of plastic packaging material is partially caused by the increasing use of high value added packaging of perishables: retail chains use to a larger extend modified atmosphere packaging for perishables like meat, poultry of seafood. Modified atmosphere (altered O_2 and CO_2 concentrations inside the packaging) is used to slow down spoilage processes and to offer a product with a longer shelf life to the customer.
A possible solution to the problem of the increasing waste stream of packaging materials is the use of compostable / bio-degradable packaging materials for MA packaging of meat products. AVEBE Paragon laminates and Apack trays offer this possibility. A critical issue are the barrier properties of compostable packaging materials. At low relative humidities, Paragon laminates have excellent barrier properties, but at higher relative humidities (which are always present in food packaging), the permeability of the laminates increases significantly above the permeability of the materials currently used in MA packaging of meat products. Aim of the study is to quantify the dimension of the problem and to assess the potential of Apack / AVEBE packages for meat products.
In order to obtain an evaluation of the performance of the Apack / AVEBE packages, the quality and performance of the packages is integrally assessed (microbial quality of the product, sensory / visual appearance the product, gas concentration inside of the packages, permeability of the packaging material).

2 Set-up of the experiments

2.1 Product

The packaging trials were carried out with two types of product: ground beef and chicken breasts. Ground beef was chosen as a highly perishable product (the average shelf life under optimal MA condition is 8 days), which is a red meat product and therefore discolorates under influence of the atmospheric gas conditions, and which is a very moist product (in a sense, a 'worst case scenario' for packaging in moisture – sensitive packaging materials). Recommended MA conditions are 60% O_2 and 20 - 30% CO_2: high oxygen concentrations extend the colour stability in display packaging, and elevated CO_2 concentrations slow down microbial growth.
Chicken breasts were chosen as a 'white meat' product with a fairly long shelf life under MA conditions (21 days). Recommended MA conditions are low O_2 concentrations (0-2%), and elevated CO_2 concentrations (20-30%) which slow down bacterial growth.

2.2 Materials

Chicken breasts were packed in Apack trays with AVEBE laminate 706 (thickness 130 μm) as coating and topseal of the tray (experiment 1), and ground beef was packed in Apack trays with AVEBE laminate 661 (thickness 101 μm) as coating and top seal of the tray (experiment 2). Each product was also packed in a standard packaging, a PET tray with a multilayer PET topseal film. In the following, the PET tray + multilayer PET topseal package is referred to as 'standard PET package'. The gas packaging was carried out on a commercial ILPRA gas packaging machine. A cellulose drip pad or a drip tray was added to all packages in order to absorb or collect moisture which is released by the product when it is placed under MA conditions. Since the moisture inside the packages will influence the barrier properties of the AVEBE laminates, we included one additional combination of packaging and superabsorbant drip pad in experiment 1: the use of superabsorbant drip pads (filled with polyacrylates) can potentially reduce the humidity in the packages (and therefore improve barrier properties). In addition, reducing the humidity in the packages can potentially slow down microbial growth. Packaged products were stored for 21 days (chicken breasts) and 10 days (ground beef) in a cool cell at 5°C and approximately 90% RH. The set-up of the experiments is shown in table 1.

Experiment 1			
Product	*Packaging*		*MA*
Chicken breasts (500g)	Standard (PET tray & top seal)	Cellulose drip pad	0% O_2,
Chicken breasts (500g)	Apack tray with AVEBE laminate 706	Cellulose drip pad	30% CO_2,
Chicken breasts (500g)	Apack tray with AVEBE laminate 706	Superabsorbant drip pad	70% N_2
Experiment 2			
Product	*Packaging*		*MA*
Ground beef (500g)	Standard (PET tray & top seal)	Drip tray	60% O_2, 30% CO_2, 10% N_2
Ground beef (500g)	Apack tray with AVEBE laminate 661	Cellulose drip pad	

Table 1: Set-up of the experiments.

2.3 Analysis

During the study the relevant material properties (oxygen permeability, water uptake of pads and trays during use), the development of the protective atmosphere in the packages and the quality of the product is evaluated.
The barrier properties of the materials are measured with a Mocon Oxtran 2/20 according to ASTM norm D3985. The gas composition inside the packages is monitored with a Chrompack gas chromatograph. Water uptake is determined by measuring the weight increase of pads and trays. The storage period of the chicken breasts was 21 days; the product quality was assessed on day 1, day 3, day 7, day 10, day 14, and day 21. The storage period of the ground beef was 10 days; the product quality was assessed on day 1, day 2, day 3, day 7, and day 10. The quality of the product is assessed by several criteria: a basic sensory evaluation is carried out to determine off-odours and discoloration.

The colour of the product is analysed with a L*a*b* meter. The surface pH of the product is measured on several position with a pH meter. The microbial quality is examined by determining the total count of lactic acid bacteria (LAB) and the total mesophile aerobic count. The microbial analysis is carried out by an external company (Conex in Ede).

3 Results

3.1 Barrier properties

The oxygen permeability of the packaging materials was measured at 23 °C and 85% RH. Measurements were carried out on the topseal films 661 and 706, on the topseal PET laminate film of the standard packages, and on the bottom part of the Apack trays laminated with film 661 and 706 as well as on the bottom part of the PET tray of the standard package. A good control of the relative humidity on the 'tray' side of the Apack trays laminated with AVEBE films is difficult due to the high porosity of the Apack trays which prevents a good seal from the environment at the side of the Apack material; the measurements can therefore only yield an estimate of the barrier (which is suitable to determine whether or not the AVEBE film is damaged during lamination). The results of the measurement are summarised in table 2.
Measurements on AVEBE Paragon laminates carried out in earlier studies showed two remarkable properties of these films: the O_2 permeability depends strongly on the relative humidity (increasing the RH from 40% RH to 85% RH results in an increase of the O_2 permeability of the film by a factor 100), and the laminates show at high humidity an extraordinary selectivity (the ratio of CO_2 permeability and O_2 permeability):. the films are by a factor 10 – 15 more permeable for CO_2 than for O_2. Commodity polymers (PE, PP) show a selectivity of 4.

Sample	RH in %	O_2 permeability in ml/m² day bar	Thickness in μm	Q_{100} (O_2 permeability for a 100 μm sample) in ml/m² day bar
Film 661	85	531 ± 18.8	101.5 ± 3.1	538 ± 25.6
Film 706	85	406 ± 0.5	130.6 ± 1.7	530.5 ± 7
Tray 661	84	142.8 ± 0.4	n.a.	n.a.
Tray 706	78	71.0 ± 0.2	n.a.	n.a.
PET topseal laminate	85	49.7 ± 0.08	26.1 ± 0.2	13.0 ± 0.08
PET tray	85	42.6 ± 0.4	456 ± 20	194 ± 8.7

Table 2: Summary of the permeability of the investigated materials.

The results show that the AVEBE films are about a factor 10 more permeable for oxygen than the standard packaging materials used in MA packaging of meat products. Laminating the AVEBE films onto Apack trays improves their barrier properties. From the experiments it is difficult to deduce what causes the improvement of barrier properties. Vacuum – forming the films into the trays stretches the films and possibly induces crystallisation, which would improve barrier properties. Apack trays, on the other hand, can absorb moisture; it is possible that the moisture content of the films is lower due to the moisture absorbing effect of the Apack tray material. This also could explain the improved barrier, since the barrier properties of AVEBE films improve drastically with lower moisture content.

3.2 Development of the gas concentrations inside the packaging

The gas composition of the headspace was determined at the assessment moments (see fig. 3). Figure 1 displays the development of the O_2 and CO_2 concentrations in the packages with chicken breasts.
Three phases can be distinguished in the development of the gas concentrations inside of the packages: in phase 1 (until day 1), the CO_2 concentration drops rapidly due to the absorption of CO_2 in the product. In phase 2 (day 1 until day 8), the CO_2 concentration decreases and the O_2 concentration increases due to permeation through the packaging material. In phase 3 (from day 8 onwards), CO_2 concentrations increases and O_2 concentrations decreases due to bacterial activity. Permeation occurs in all phases, but is superimposed by absorption and bacterial activity in phase 1 and phase 3.
The results reflect the higher permeability of the Apack / AVEBE system: The gas concentrations in these packages come closer to the atmospheric conditions (0.03 % CO_2 and 21% O_2) than the gas concentrations in the PET packages. However, the Apack / AVEBE trays perform surprisingly well considering their moisture sensitivity. Oxygen concentrations reach at maximum approximately 5% (compared with PET: 1.5%). The rapid decrease of the CO_2 concentrations is caused by the high selectivity of the AVEBE laminates.

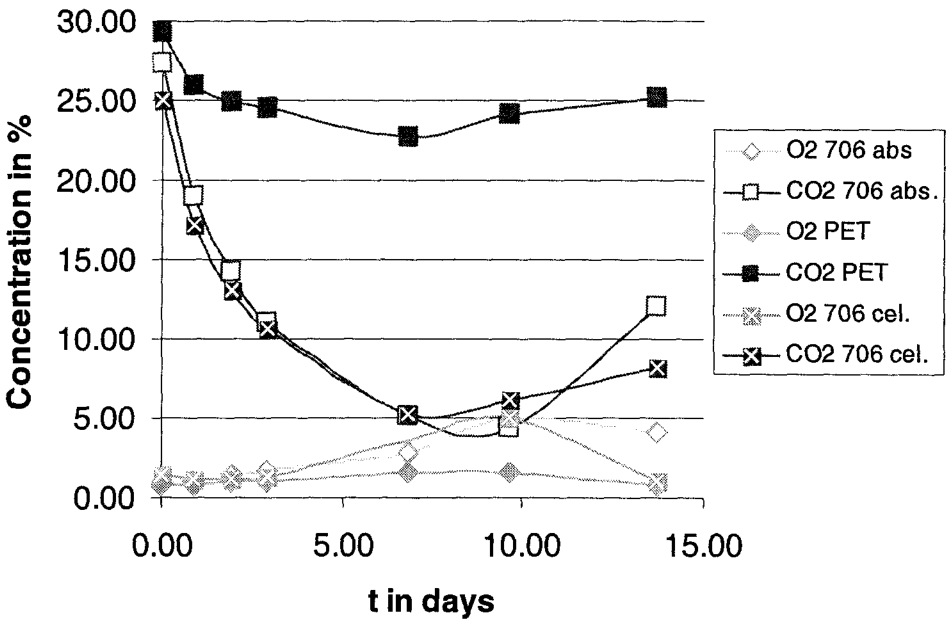


Figure 1: Development of the O_2 and CO_2 concentrations in the headspace of packages containing chicken breasts; **PET:** Pet tray and topseal; **706 cel.:** Apack tray laminated and sealed with film 706 with a cellulose drip pad; **706 abs.:** Apack tray laminated and sealed with film 706 with a super absorbant drip pad. Initial gas concentrations: ~1 % (rest)oxygen, 30% CO_2, rest: N_2.

In figure 2 the development of the gas concentrations in the packages containing ground beef is displayed. The gas concentrations in the PET packaging remain fairly stable until day three, when CO_2 concentrations start to rise and O_2 concentration start to drop which indicates the onset o microbial activity. The CO_2 concentrations in the APACK / AVEBE trays drop moderately during the first three days (from ~28% CO_2 to 20% CO_2) before the start to rise due to microbial activity. Remarkable is the drop of the O_2 concentrations in the packages after day 2. Since no similar drop in CO_2 concentrations is observed, it cannot only be explained by permeation through the packaging material. An interaction between product (e.g. microbial activity) and the gas composition is likely which leads to additional changes in the gas concentrations.

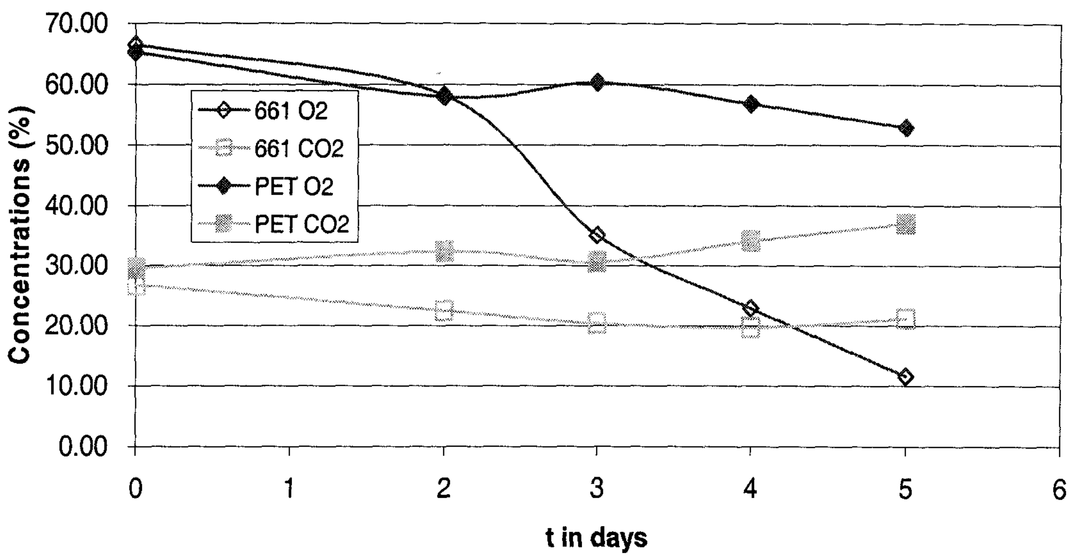


Figure 2: Development of the O_2 and CO_2 concentrations in the headspace of packages containing ground beef; **PET:** Pet tray and topseal; **661:** Apack tray laminated and sealed with film 661 with a cellulose drip pad. Initial gas concentrations: 60% oxygen, 30% CO_2, rest: N_2.

Figure 3: Measurement of the gas concentration in the packages for ground beef with a chrompack gas chromatograph.

3.3 Product quality

3.3.1 Sensory evaluation (odour and colour), colour measurements

After opening, the sensory quality of the product was assessed (off odours: yes / no; discoloration: yes / no). The colour was measured with the L*a*b* meter in average at 4 positions in order to obtain a more objective assessment of developments in discoloration. Table 3 shows the sensory evaluation of chicken breasts, table 4 the sensory evaluation of ground beef.

Day	Off - odour			Discoloration		
	PET	706 cel.	706 abs.	PET	706 cel.	706 abs.
1	**no**	**no**	**no**	**no**	**no**	**no**
3						
7						
10		**yes**[1]				
14			**yes**[1]			
21	**yes**[1]				**yes**	**yes**

[1]): 'Garlic' off odour.

Table 3: Sensory evaluation of chicken breasts.

For chicken breasts, the different packaging concepts resulted in different moments when off-odour was noted. The product packed in the standard packaging showed off odour on the 21st day after packaging; the product packed in the Apack / AVEBE tray with a cellulose drip pad was rejected because of off odour on day 10. Adding a superabsorbant drip pad to the tray delayed the occurrence of off odour: the chicken breasts were rejected on day 14. Chicken breasts are less sensitive to dicolouration than ground beef; the product packed in the Apack / AVEBE trays showed off colours only on day 21.

Day	Off - odour		Discoloration	
	PET	661 cel.	PET	661 cel.
1	**no**	**no**	**no**	**no**
2				
3				**yes**
7	**yes**[2]	**yes**[2]		
10			**yes**	

[2]): Fermented off odour.

Table 4: Sensory evaluation of ground beef.

Figure 4: Discoloration of ground beef after 7 days of storage.

The ground beef was rejected because of off odours on day 7 for both types of packaging. In contrast to the chicken breasts, the colour of ground beef is less stable and sensitive to sub-optimal MA conditions. The beef packed in the Apack / AVEBE trays turned brownish on day 3, whereas the colour of the beef packed in the standard packaging became unacceptable on day 10. In order to quantify the colour changes of ground beef, the colour of the product was determined with a L*a*b* – meter according to the L*a*b* colour scale. The value L* represents the 'lightness' of the colour, the value a* shift in colour from red to green (positive a* values: red, negative a* values: green), and the value b* represents the shift of the colour from yellow to blue (positive b* values: yellow, negative b* values: blue). The L*a*b* scale was designed to 'match' the colour perception of the human eye: large differences in L*, a*, and b* values correspond to colours which are perceived drastically different; L*, a*, and b* values which are close to each other correspond to colours which are perceived as similar. Changes in colour during ageing and spoilage of the product can also be expressed by combinations of L*, a*, and b*. The value of a*/b*, the 'hue' - value atan (b*/a*), and the chroma value $(a^{*2}+b^{*2})^{1/2}$ can be used to characterise changes in colour. The brown discoloration of the ground beef could be well characterised by changes in a*/b*, or the 'hue' - value atan (b*/a*) (see figure 5 and table 5).

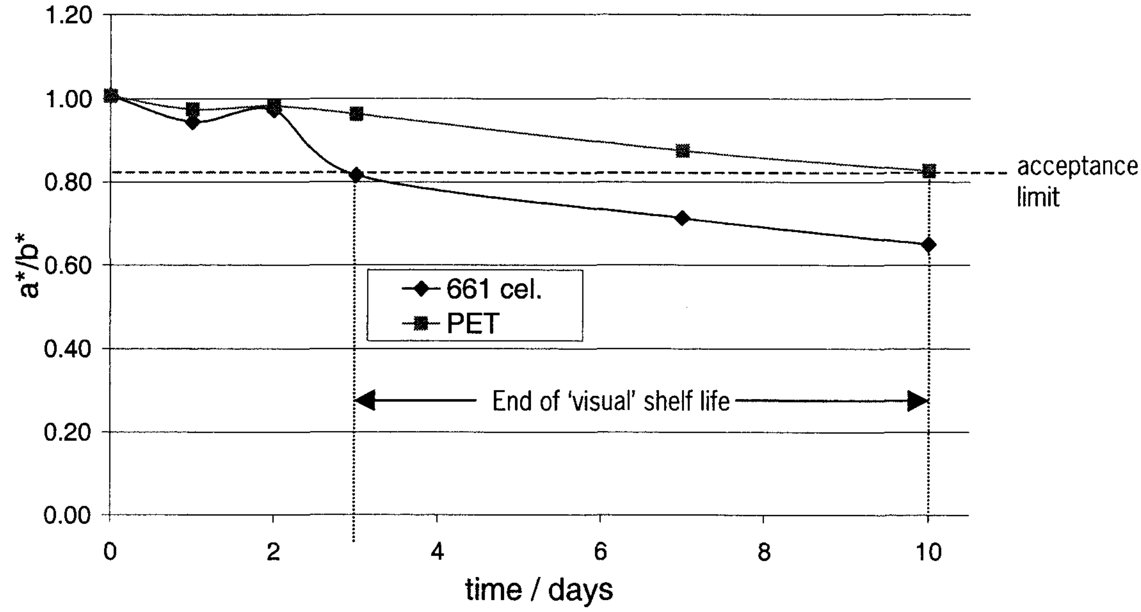


Figure 5: Factor a*/b* for the surface colour of ground beef as a function of time.

Packaging	Off-Color (days)	Hue	Chroma	a*/b*
661 cel.	3	50.8	25.7	0.82
PET cel.	10	50.4	24.7	0.83

Table 5: Hue, chroma and a*/b* values of ground beef on the day of rejection due to off colours.

3.3.2 Microbiological evaluation

Both products were tested during the storage period on the number of colony forming units (cfu) of lactic acid bacteria (LAB) and aerobic mesophiles (the total aerobic count). In the Netherlands, the product is regarded as spoiled if the total cfu count per gram product exceeds 1×10^6. Under aerobic conditions, the aerobic mesophile count would represent the total number of cfu's which needs to be tested. However, certain types of lactic acid bacteria grow specifically under non-aerobic conditions (i.e. under MA conditions). In order to take into account the cfu count arising from anaerobic bacterial growth, the LAB count was determined. Strictly speaking, the product is viewed as spoiled, of the sum of both counts exceeds 1×10^6.
In the tests, the upper experimental detection limit of LAB cfu's is 1×10^6 cfu/g (which coincides with the threshold of spoilage). The upper experimental detection limit for aerobic mesophile cfu's is 1×10^8 cfu/g.

Chicken breasts
In figure 6, the growth of lactic acid bacteria on the chicken breasts is displayed. In the Apack / AVEBE packages, a rapid growth of LAB sets in on day 7. The absorber pad in the Apack / AVEBE packages did not result in a slowing down of the growth of LAB. The growth of LAB in the standard packages is delayed by an additional three days, here the growth sets in on day 10.
Figure 7 displays the growth of aerobic mesophile micro-organisms on the chicken breasts. Growth sets in on day ten; the growth rate in the standard PET packages is however much lower than in the Apack / AVEBE packs.

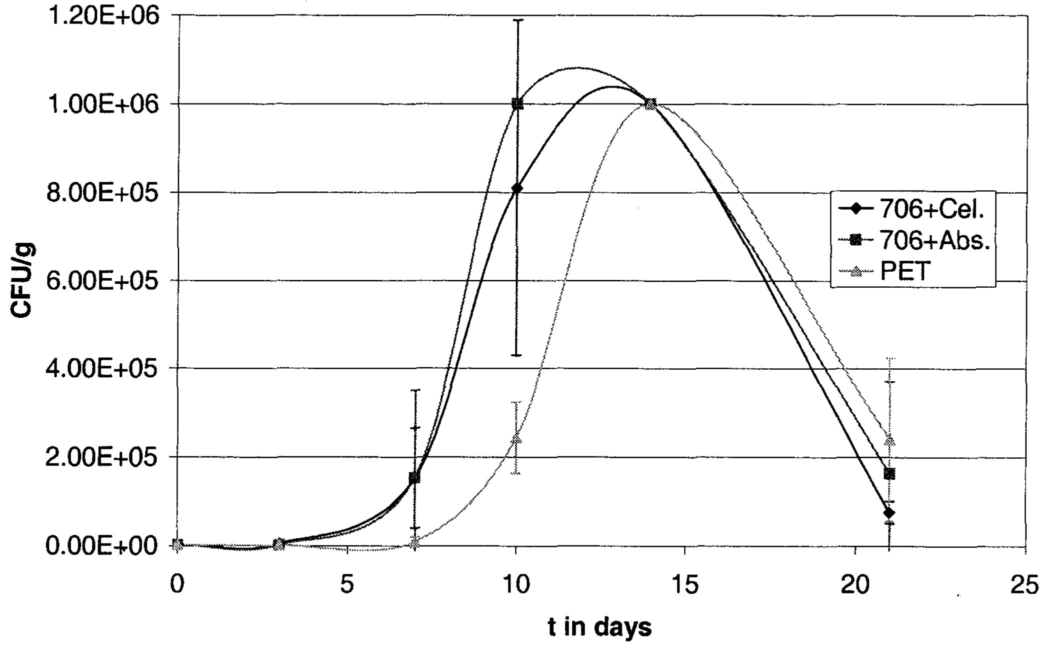


Figure 6: Lactic acid bacteria colony forming units per gram product as a function of time in different packages for chicken breasts.

The three days earlier onset of growth of LAB and the higher growth rate of aerobic mesophile bacteria are most likely related to the higher permeability of the Apack / AVEBE packages. The observed off-odour in the chicken packages on day 10 and 14 coincide with high bacterial counts; in contrast to the sensory evaluation, the microbial tests did not show any effect of the super absorbant drip pad.

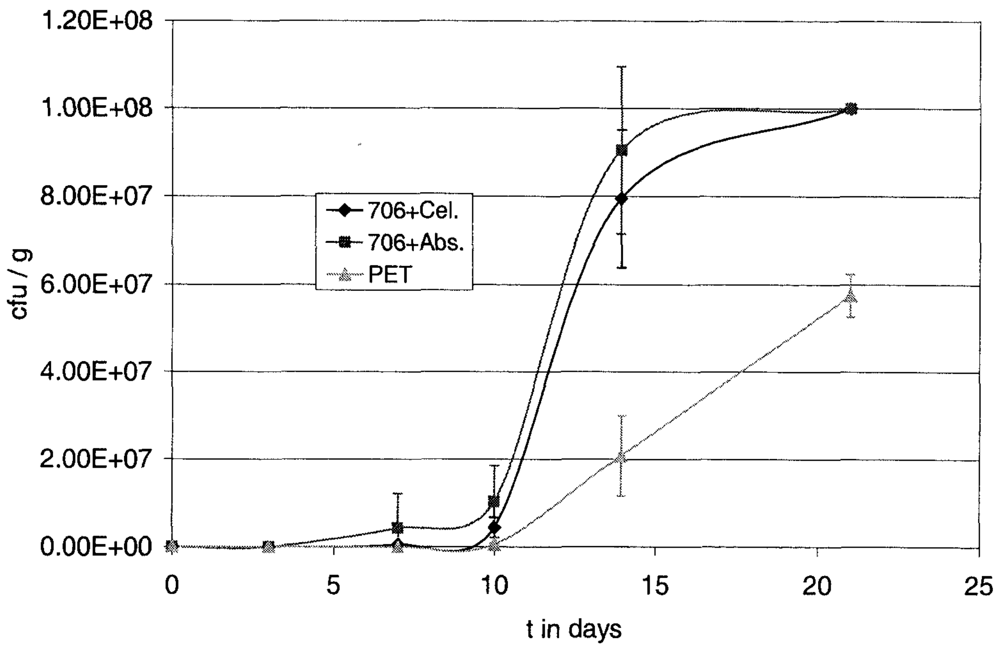


Figure 7: Aerobic mesophile colony forming units per gram product as a function of time in different packages for chicken breasts.

Ground beef

The counts of LAB cfu's on ground beef are displayed in figure 8. In both types of packages, a rapid growth sets in on day 2. There are only marginal differences between the PET packages and the Apack / AVEBE packages. The growth of aerobic mesophile micro-organisms sets also in on day two. The total counts of aerobic mesophiles are lower in the PET packages than in the Apack / AVEBE packages, which indicates a sub-optimal modified atmosphere in the Apack / AVEBE system due to its higher permeability.

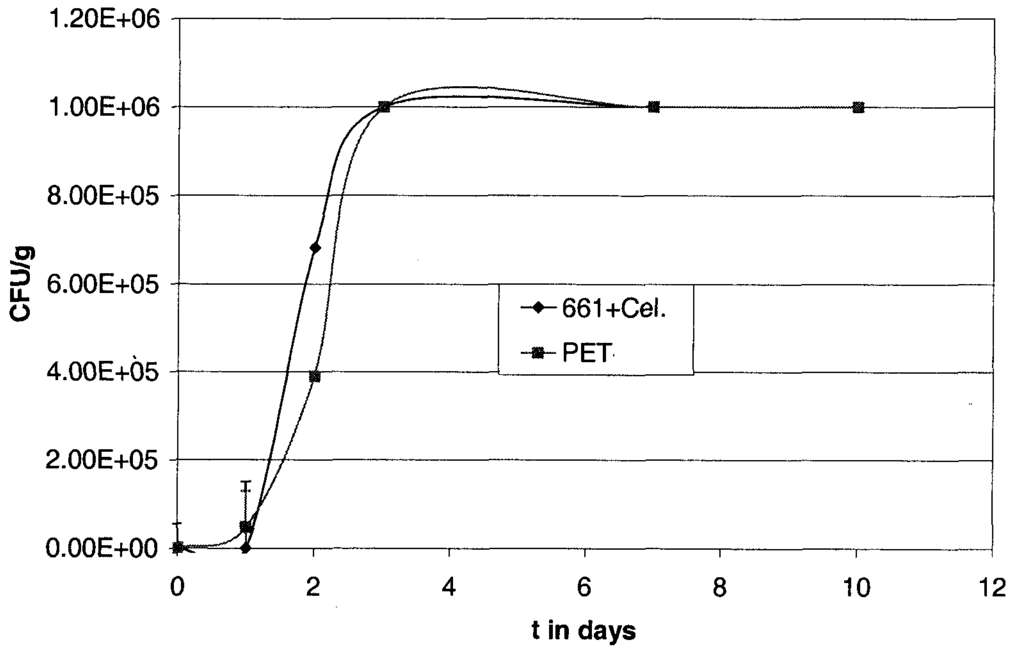


Figure 8: Lactic acid bacteria colony forming units per gram product as a function of time in different packages of ground beef.

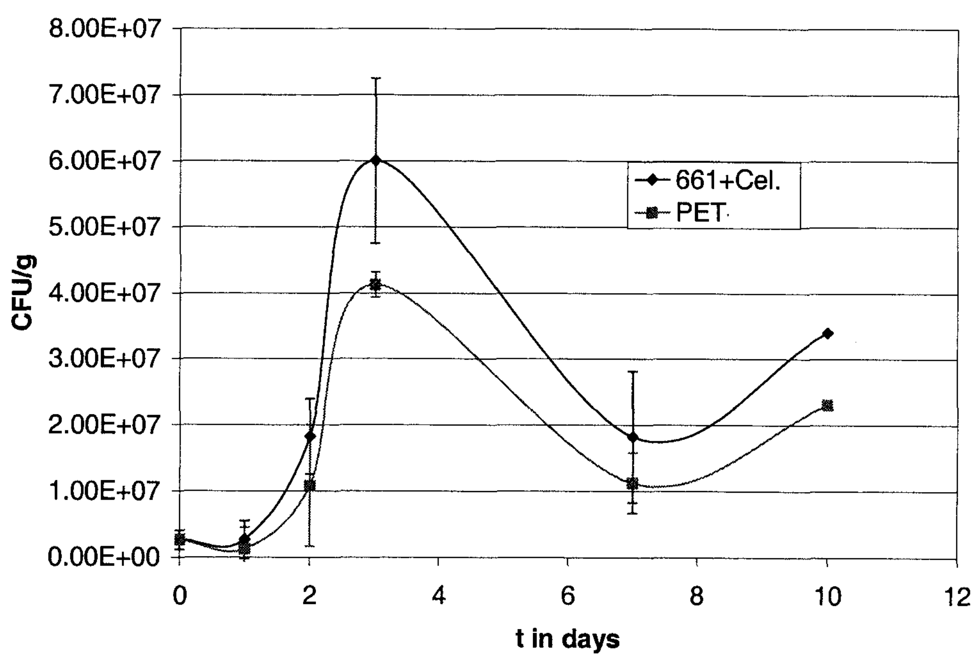


Figure 9: Aerobic mesophile colony forming units per gram product as a function of time in different packages of ground beef.

The differences in microbiological quality of ground beef packaged in different packages are less clear as for the chicken breasts. Ground beef is in comparison with chicken breasts highly perishable, spoilage occurs on a much shorter time scale (and the influence of different packaging types is therefore more difficult to detect). The rapid growth of the LAB counts on day two and the rather high aerobic mesophile counts at the packaging day in both packages indicate that the initial quality of the beef was sub-optimal (e.g. it underwent some temperature abuse before packaging). This assessment confirms investigations of consumer organisations, who stated that the microbial quality of ground beef needs to be improved. Modified atmosphere packaging has the largest impact on the shelf life of the packed product, if the initial quality of the product is good. If the initial quality of the product is sub-optimal, the effect of modified atmosphere is less, and differences between different packages will be less obvious.

3.3.3 Surface pH

The pH of the product surface can be used to monitor the interaction between modified atmosphere and product and the development of the quality of the product. The elevated CO_2 levels in the modified atmosphere will lead to an initial decrease of the pH. In addition, bacterial growth is often accompanied by changes in the (surface) pH: LAB produce lactic acid which lowers the pH. A measurement of the surface pH can therefore also yield some insight into spoilage processes.
The surface pH of chicken breasts and ground beef are displayed in figure 10 and figure 11. In an initial phase (day 0 – day 2) the surface pH drops due to the absorption of CO_2 from the modified atmosphere. This phase is followed by a recovery phase; the surface pH drops again at the point where the growth of LAB sets in (approximately day 7 for the chicken breasts and day 2 for the ground beef). The surface pH of the chicken breasts rises again after day 10 when the LAB counts drop (LAB produce lactic acid and thus decrease the pH) and the aerobic mesophile counts increase. The pH values of the chicken breasts packaged with a super absorbant drip pad undergo less variations than the pH values of chicken breasts packaged with cellulose drip pads. The super absorber (the sodium salt of polyacrylic acid)can possibly act as a buffer which stabilises the pH.

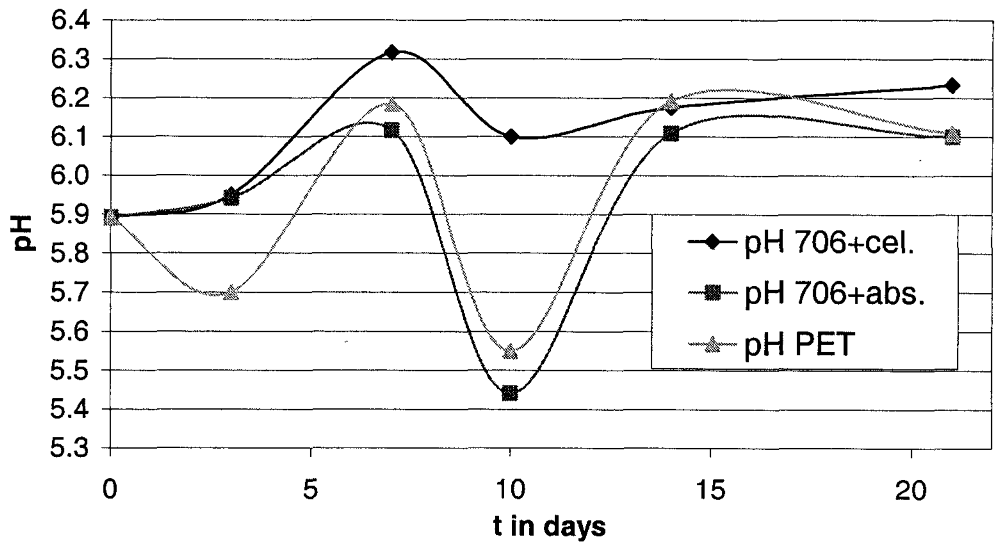


Figure 10: Development of the surface pH of chicken breasts packed in different packages.

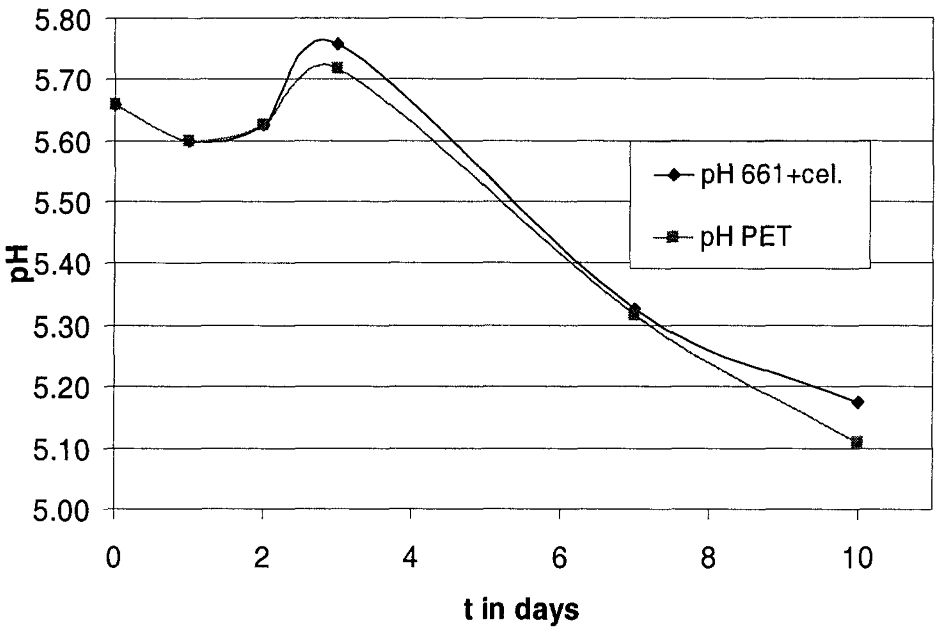


Figure 11: Development of the surface pH of ground beef packed in different packages.

3.3.4 Moisture loss of the chicken breasts for different drip pads

In the packages of the chicken breasts, two different types of drip pads were used: in addition to the standard cellulose drip pad, a drip pad was used which actively absorbs moisture. A super absorbing polymer (polyacrylate) was integrated in this drip pad. The water uptake of the pads as a percentage of the weight of the packaged chicken breasts is displayed in figure 12.

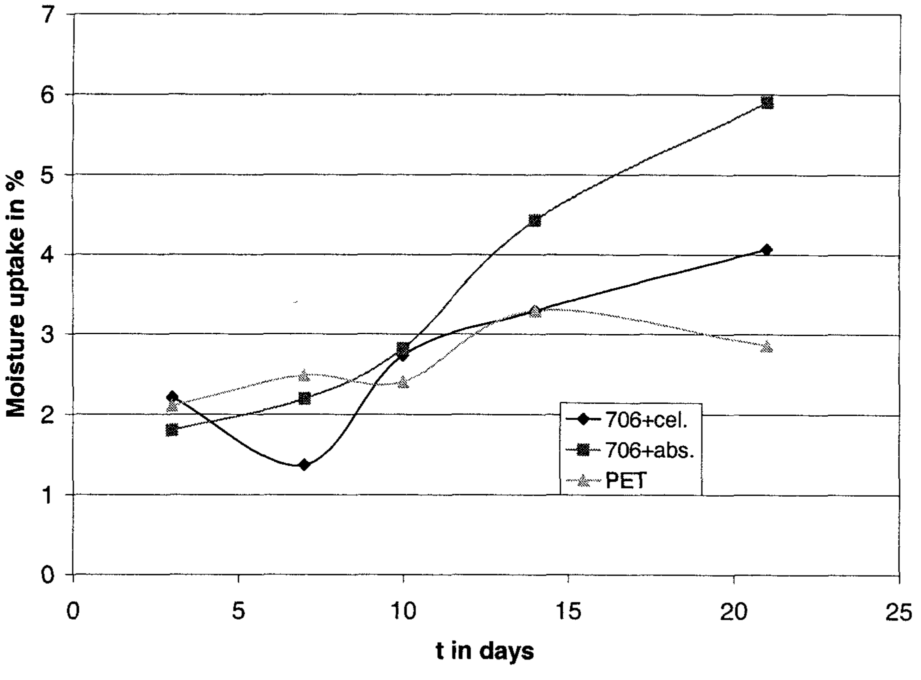
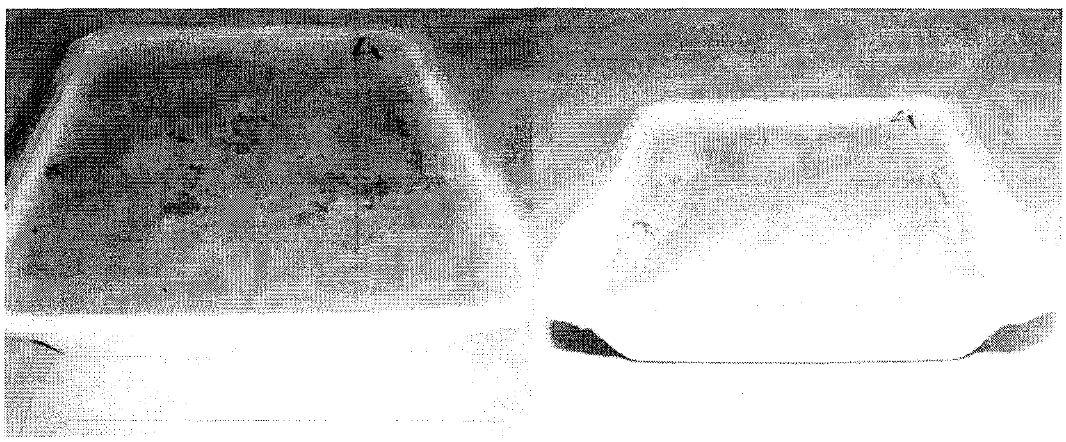


Figure 12: Moisture uptake (drip) of the drip pads in different packages. **PET:** Pet tray and topseal; **706 + cel.:** Apack tray laminated and sealed with film 706 with a cellulose drip pad; **706 + abs.:** Apack tray laminated and sealed with film 706 with a super absorbant drip pad. The moisture uptake is presented as percentage of the weight of the packed product.

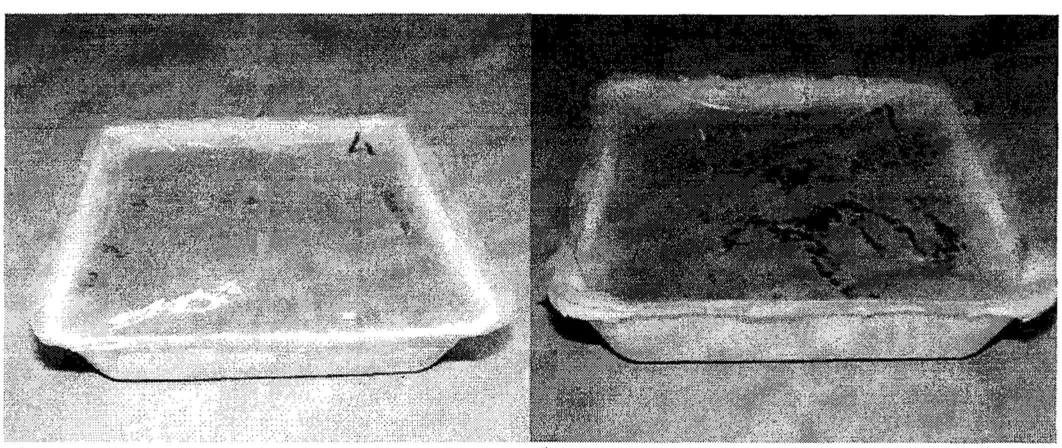
Compared with the cellulose drip pad, the super absorbant drip pad removes more moisture from the product: After 20 days, the chicken breasts packed with a super absorbant drip pad lost 6% of weight (the chicken breasts packed with cellulose drip pads lost 3 – 4 % of their weight). In the initial phase of the storage, the moisture loss of the chicken breasts packed in the Apack / AVEBE packs are slightly less than the moisture loss of the chicken breasts packed in the PET packages. This can be explained with the higher permeability of the Apack / AVEBE packs (in particular for CO_2): CO_2 causes moisture loss, and the CO_2 concentrations in the PET packages are higher than in the Apack / AVEBE packages.

3.4 Mechanical stability of the Apack / AVEBE packages

After packaging, CO_2 dissolves in the product, and (in particular for the AVEBE laminates with their high permeability for CO_2) CO_2 permeates through the packaging material. As a result, the pressure inside the packages drops, and packages can collapse. In order to avoid the collapsing, the packaging (in this case, the Apack tray and the bond between AVEBE film and tray) needs to provide sufficient mechanical strength.



Packaging day after one day



after two days after three days

Figure 13: Collapse of the packages due to low pressure caused by absorption and diffusion of CO_2.

During storage in the cooling cell at 5°C and approximately 90% RH, the Apack trays absorbed moisture, and softened. As a result, their mechanical strength weakened, the material cracked and the film delaminated from the tray. In comparison with the trays stored under dry conditions, the trays stored under humid conditions felt 'soft'.
Furthermore, the weakening of the trays resulted in about 20% of the cases in leakage: the protective atmosphere was lost.

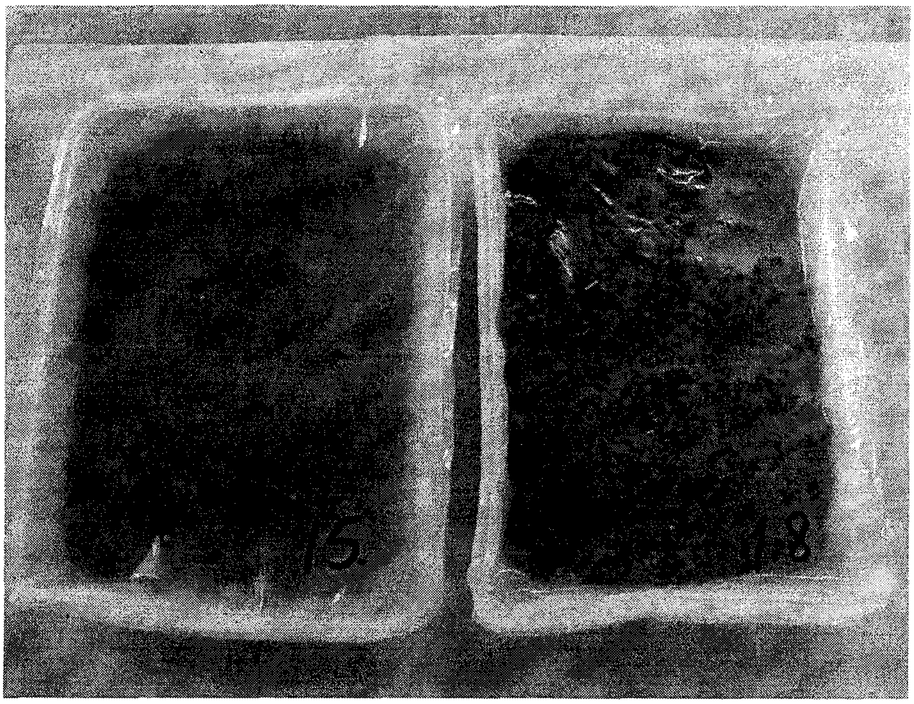


Figure 14: Apack / AVEBE trays leaking (left) and collapsed (right) under the influence of low pressure.

4 Summary of the experimental results

Chicken breasts and ground beef were packaged under modified atmosphere in different types of packaging (standard PET and Apack / AVEBE topseal trays) and drip pads (cellulose and super absorbant drip pads). The performance of the packaging concepts were evaluated with several criteria. The effects of the different types of packaging on the criteria which determine the shelf life of the product are summarised in table 6.

Evaluation	Shelf life chicken breasts, 5°C			Shelf life ground beef, 5°C	
	PET cel.	706 cel.	706 abs.	PET	661 cel.
Odour	21	10	14	7	7
Discoloration	>21	21	21	10	3
Microbial quality	14	10	10	2	2

Table 6: Summary of the quality indices evaluated in order to determine the shelf life of the products in different packages.

The results of the evaluation of the product quality show that the largest differences between the standard packages and the Apack /AVEBE packages occur at the sensory evaluation of the product: Compared with product packed in standard PET packages, chicken breasts packed in Apack / AVEBE packages are rejected 10 (cellulose drip pad) respectively 6 days (superabsorbant drip pad) earlier because of off-odour, and ground beef is rejected 4 days earlier because of discoloration. The differences in microbial quality are less striking: the chicken breasts packaged in PET packages were 4 days longer acceptable than the chicken breasts packaged in Apack / AVEBE packages, and the ground beef was rejected after two days in both packages. Remarkable is that due to bacterial growth the products in general failed to reach the expected shelf life. Only the rejection dates purely based on the sensory evaluation of product packaged in standard PET packages came close to the expected shelf lifes.

Summarising the results on product quality, one can conclude that the Apack / AVEBE packages lead primarily to a reduction of the 'sensory' shelf life of the product (off odours and discoloration, i.e. quality criteria which the consumer uses). The advantage of the standard PET package shrinks or disappears, if the microbial quality of the product is included into the evaluation. In our tests, the Apack / AVEBE package seems to be the more 'honest' package: the end of the sensory shelf life coincides with the

end of the 'microbiological' shelf life, whereas in the standard PET packages the sensory quality of the product suggested to the consumer still an acceptable product when the microbiological state of the product was already doubtful.
One has to keep in mind that the effect of an MA packaging on microbial growth (and, therefore, differences between different types of packaging) depend strongly on the initial quality of the product; good initial quality will result in a clear extension of the shelf life by MA, and for bad initial quality there will be no effect of MA (and thus no detectable differences between an optimal and sub-optimal MA package). For a conclusive evaluation of the performance of Apack / AVEBE trays for ground beef, the packaging trials would need to be repeated on a larger scale in order to take effects of varying initial quality of the product into account (which was not the objective of the current study).
In addition to the product quality, the performance of the packaging material was evaluated. The laminated trays and films are suitable for the use in a gas packaging machine. The shelf life of the product and the MA conditions inside the packages can be improved, if the barrier properties of the AVEBE films under humid conditions are improved. Another problem is the moisture sensitivity of the Apack trays: during storage under high humidity, the trays soften and loose their mechanical strength. Absorption and diffusion of CO_2 (where the latter is in particular high for AVEBE films) lead to a collapse of the trays and in some instances to leaking trays. Handling of the softened trays (e.g. stackability) can also be problematic.
In summary, the study showed some potential and some weaknesses of the Apack / AVEBE trays. The packages could maintain a protective atmosphere despite their sensitivity for moisture (although the effects of the higher permeability of the materials are still visible in a shorter shelf life of the product). The first test of the bio-degradable packaging concept under 'real life' conditions also showed some weaknesses, in particular the effect of moisture on the mechanical stability of the packages. One should, however, emphasise that a first test of a packaging concept very often shows weaknesses which can be corrected in the further development of the packages. The aim of packaging trials during the development phase of a packaging is rather discovering these weaknesses than carrying out a 'final test' of a completed concept.

5 Recommendations

The consumer evaluates the product in the shop by its visual appearance and by the 'feel' of the package: meat has to have the 'right' colour (therefore, the top seal film has to be absolutely clear), and a crisp and clear packaging material is associated with a fresh product (as an example: potato chips or fresh cut vegetables are always packaged in rustling and 'crisp' films, and never packaged in soft, rubber-like films). In particular in the field of consumer acceptance, the Apack / AVEBE packages need to make some improvements. The top seal films are not clear, but clear topseal films are an absolute necessity in order to present the product to the consumer. Softened and collapsed trays do not communicate to the consumer that the package contains a fresh product (even if the quality of the product is perfect).
In order to improve the performance and future consumer acceptance of the Apack / AVEBE packages, the following steps are necessary:

- The mechanical performance of Apack trays under humid conditions has to be improved in order to avoid collapse and leakage of the package and in order to achieve the right 'feel' of a package for fresh products which the consumer expects.
- The transparency of the AVEBE laminates needs to be improved such that the consumer can see the product and assess the 'quality' of the product.

The following steps are advisable in order to improve the market position of Apack / AVEBE packages with respect to the existing packaging concepts:

- An improvement of the barrier properties of the AVEBE laminates by a factor ten (with respect to the permeability of the topseal films) would be desirable. This would most likely result in a performance of the packages which is comparable to the performance of the existing packages.
- Alternatively, retailers and consumers need to be convinced that the advantage of a compostable packaging outweighs the disadvantage of a shorter shelf life; after all, the tests showed that for a good initial quality of the product, the Apack / AVEBE system still resulted in a 'manageable' shelf life.

Some technical solutions can be applied in order to improve weaknesses of the Apack / AVEBE packages:

- Using a larger volume packaging will decrease the danger of packaging collapse due to absorption of CO_2 in the product and will lead to less decrease in CO_2 concentrations. The loss of CO_2 by permeation will however persist, if the barrier properties of the films are not changed.
- For products which require a high initial O_2 or CO_2 concentration, these concentration can be increased above the recommended values in order to compensate for losses by permeation. It should however be checked, whether or not an exposure to higher initial gas concentrations compromises the product quality. In addition, higher initial CO_2 concentrations will aggravate the effect of collapsing packages caused by CO_2 permeation.