PACKAGING OF MUSHROOMS
Suitability of SUNTEC S H-100H film for packaging of mushrooms

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Summary.

The suitability of Suntec S H-100H film for the packaging of mushrooms is tested by comparing it with a poly ethylene (pe van de Windt) and a pvc (Linwrap LBAC) alternative. The test-conditions are derived from non-optimal situations as they can occur in the distribution chain. The mushrooms are kept at 8 and 18°C for a maximum of 6 days, and judged on colour, stipe elongation, cap opening, weight loss and water condensation on the film. As a control, unwrapped mushrooms are also observed. There is a distinct difference in the Modified Air conditions in the packages depending on the type of film. The average carbon dioxide concentration declines for the tested pe- to Suntec- to pvc-film from high to low levels respectively. The variation in the quality characteristics depending on the film-type is reduced by anaerobe conditions and is generally small. It is seen that the Suntec film S H 100H (11 microns) is a very suitable overwrapping film for 250 g prepacks of mushrooms. Whiteness and development of the mushrooms is comparable to Linwrap LBAC (pvc) and better than a van de Windt pe film (both 16 microns). Retardation of stipe elongation by Suntec S H 100H is better than that achieved by the other two films.

1. Introduction

In 1989 the production of mushrooms in the Netherlands was estimated at 135 million kg produce. Marketing research indicates that ca. 50 % of the total yield is sold as fresh produce. The other mushrooms are processed. In supermarkets and groceries most fresh mushrooms are packed in small retail packages containing 250 g. produce each. In 1989 the share of retail packages (pre-packs) in the total amount of the fresh mushroom market was about 80%. The prediction for 1992 is a yield of 200 million kg (Rudolphy 1991).

The pre-pack is a blue polystyrene punnet overwrapped with stretch film or capped with a perforated polystyrene lid. The size of the punnets is 140*120*57 mm. In order to avoid mechanical damage, to facilitate handling and to obtain optimum shelf-life during distribution, mushrooms are put directly in these punnets at harvest. Generally growers transport their mushrooms to wholesalers or to auctions in open punnets. There the product is collected and prepared for the next link in the distribution chain. This preparation includes cooling, wrapping and sealing of the packages by means of packaging machines. These packaging machines for overwrapping and sealing are supplied with thin clear plastic films.
Until 1990 a pvc-film: type Borden Auto-RMFA with a thickness of 16 microns was commonly used as a overwrapping material for mushroom pre-packs.
Due to air pollution problems when burning waste pvc-material (dioxynes) some supermarket chains decided to banish out of their stores pvc as a packaging material. This situation forced all mushroompackers to apply a new more environmentally friendly wrapping film which equals the properties of the conventional pvc-film. One answer to this subject was that some wholesalers use an alternative package system. On their package machines the punnets are closed (welded) with a perforated transparent polystyrene cap. In order to introduce this system packers were forced to buy new relatively expensive packaging machines. Another alternative is given by N.V. Asahi Barrialon (Europe) S.A. from Brussels-Belgium. They claimed to have an alternative non-pvc film suitable for the packaging of mushrooms. The name of the film is Suntec S c-type H-100H and consists of poly-ethylene. Pe as a waste material is mentioned non-polluting as it can be burned relatively clean without causing toxic gases. This is called more environmentally friendly as pvc. Asahi Barrialon asked ATO-DLO (Wageningen-The Netherlands) to investigate the effects of Suntec film on the quality (keepability) of pre-packed mushrooms. Therefore we have performed experiments to observe the quality of mushrooms preserved under different conditions of packaging.

1.1 Effects of packaging on quality of mushrooms.

Mushrooms have a respiratory metabolism, which shows that oxygen is consumed and carbon dioxide is produced. As a result of the packaging method there will be a change in gaseous composition in the wrapped punnet. The air exchange is restricted by using a overwrapping film.

Carbon dioxide concentration is increased and oxygen is depleted. After about 24 h. a rough equilibrium is established. In equilibrium the gas exchange through the overwrapping film equals the respiration rate of the produce. This is known as Modified Air Packaging (MAP). MAP can effect product quality positively. However it is also possible that toxic gaseous levels occur, so that deterioration is accelerated instead of retarded. Earlier work (Murr 1975, Nichols 1973, Mac Canna 1967, Czapski 1986) showed that the following quality assessments are influenced by the internal atmosphere:

- retardation of development (stipe and pileus)
- water loss
- internal and external browning of the pileus
- blotchiness from microbial contamination
- toughness.

Dutch mushrooms are attractive for the European consumer because of their superior whiteness. From a commercial point of view this is the most important quality factor (Rudolphy 1991). It is known that high carbon dioxide levels inside the pre-packs can accelerate brown colouration (Nichols 1973). For that reason wrapping films for mushrooms should have a high permeability for this gas. Mushrooms of the species Agaricus Bisporus have a relatively high respiration rate compared to fruits and vegetables. Respiration activity is the cause of the increase of the CO_2-concentration in the overwrapped pre-pack. The high respiration rate and the sensitivity for high CO_2 levels indicate that the keepability of the packed mushrooms is very sensitive to the permeation characteristics of the film.

Elongation of the stipe and or development of the cap is the second important quality factor. These should be minimized. Retardation of development can be achieved with very low oxygen (O_2) concentrations in combination with high carbon dioxide (CO_2) levels (Czapski 1986, Murr 1975). Murr found that CO_2 inhibited mushroom growth but that 5% CO_2 while inhibiting cap expansion stimulated stipe elongation. The role of O_2 is not fully understood yet. Murr found a stimulatory effect of 4% O_2 on cap opening and a retarded effect of very low concentrations (< 1%). Thus the CO_2-concentration should balance between high levels in order to reduce development and to low levels in order to retard browning of the mushroom.

Condensation of water on the packaging material and on the product give brown microbial blotches especially where product and package material contact each other. Besides that the consumer wants to see and judge the freshness of the product. This requires a transparent film without watercondensation on the film. So condensation of waterdrops on the wrapping film should be avoided not only for quality aspects but also from a marketing point of view.

2. Experiments

In order to test the suitability of Suntec S H-100H film made by Asahi Barrialon as an overwrapping film for mushroom pre-packs, considering the Dutch distribution system and commercially important quality factors, an experiment was carried out with various overwrapping films, different storage temperatures and storage periods:

Variation in packaging:

- pvc-compound: Linwrap LBAC selected and obtained via Banken. Thickness: 16 micron
- pe-film: v.d. Windt selected and obtained via Banken. Thickness: 16 micron
- pe-film Suntec S c-type H-100H film: Thickness: 11 micron
- unwrapped punnets

Storage time and temperature:
The packages are stored in 8 °C and 18 °C for three and six days.

Product:
Mushrooms from the species Agaricus Bisporus strain U1 are used. This strain is the most common strain grown in the Netherlands especially for the used quality class. Produce from two different growers selected by Banken are investigated. The initial quality is class 1; size "fijn" as described by the Dutch PGF-organization.

Quality measurements:
The following quality assessments are observed:

-colour: browning of the cap
-stipe elongation and cap opening
-weight loss
-watercondensation on the film

Microclimate:
Oxygen and carbon dioxide levels in all the packages are measured several times depending on storage time.

Experiment:
The experiment is carried out twice:

exp. 1: 1-10-1991 till 7-10-1991
exp. 2: 29-10-1991 till 4-11-1991

Thus for the complete experiment product from 4 growers is involved.

3. Material and methods

Mushrooms

In both experiments the mushrooms were collected and selected by Banken champignons at Batenburg. The mushrooms were picked on monday about 24 hours before package them at ATO on tuesday. At Bankens' the mushrooms were placed in a cold store (4 °C) during the night (approx. 14 hours). Preparation from the packages such as weighing, length measurements, overwrapping and heatsealing took about 3 hours. From that moment the mushrooms were placed at 8°C and 18°C in large cold stores (2*3*3 m.). There was no humidity control. The RH was in the range 80-90% at 8°C and 60-70% at 18°C for both experiments.

It can be assumed that the strain U1 from the cultivar Agaricus Bisporus was selected as almost any product in this quality class in the Netherlands is from that strain. The variety's are not declared by growers at wholesalers so they do not know which variety is delivered to them. It is also not known whether different flushes have been selected. The tested mushrooms were hand picked and put directly during harvest in blue punnets. Eight punnets are placed in plastic trays. From harvest till the moment the mushrooms were inspected (colour measurements) the produce was not touched at all. Handling of mushrooms can easily damage the produce. The result is browning of the touched area. To exclude effects of handling as was necessary to carry out elongation measurements we grouped mushrooms. One group for elongation measurements, the other for colour measurements.

Overwrapping and sealing:

All packages were overwrapped and heatsealed at ATO-DLO using a hand heatsealer: type Sibola KM 10. Sometimes adhesive tape was used when seals were inadequate.

Package variations:

In each treatment of the packages: time, grower, temperature we tested 4 variations: Suntec, pe, pvc and unwrapped. Four pre-packs per treatment were necessary: two (duplicate) for colour measurements and two for elongation measurements. This was necessary for reliability of the measured data. These four packaging variations were chosen while:

a) Tests so far showed that pvc: auto-rmfa was the best suitable overwrapping film for mushrooms (Nicholls 1973, Boerrigter unpublished).

b) Asahi claimed a better effect of their film Suntec compared to commercial available pe-films in the Netherlands. Suntec is also a pe-film.

c) open punnets give an indication of the colour change related to CO_2-concentrations. Dehydration and air movement along the surface of mushrooms effects also the whiteness of the mushrooms.

Both experiments consisted of 128 pre-packs:

colour * elongation * grower * temperature * storage period * package variation.

2*2*2*2*2*4 = 128 pieces.

Quality measurements:

Colour

The colour measurements have been carried out in two different ways:

-Minolta chroma-meter: CR-200

-visual inspection by a panel of 6 specialists

Minolta: The reflectance value of the surface of the pileus was determined as the mean of 25 readings per punnet. The light sensor has not been placed on blotches or dirt spots from soil. The reflectance is the quotation percentage compared to a standard Minolta white plate.
Visual inspection: Values were estimated on a scale 0-10 (0= brown-10= white). During inspection the punnets were randomized and the inspectors did not know the treatment of the object.

Development: stipe elongation and cap opening:

Measurement of the growth of the mushrooms is done by means of a Quantimet 520 computer image analysis system. The mushrooms were carefully and gently taken out of the punnets and fixed on a special designed tray. An image of the mushrooms taken sideways by a ccd-camera was digitized on the Quantimet system. A special developed ATO-algorithm enabled us to calculate the initial averaged length of every considered pre-pack. The increase of the elongation is determined by measuring the length of every mushroom at the start and on the third day respectively at the start and on the sixth day of the experiments. For the mentioned periods we used different pre-packs. These data give an accurate value of the percentage of the elongation. Immediately after unpacking the percentage open caps of the mushrooms were noted. We distinguished 3 stages in cap opening: closed (unbroken velum), open (gills exposed-velum broken) and 'gevliesd' ((gevl in table 6) velum torn but not broken).

Weight losses:

From all punnets fresh weight losses in % were calculated. A Mettler electronic balance type PE-1600 was used with an accuracy of 0.1 g.

All post-storage measurements were made immediately after breaking the film overwrap.

Gas analysis:

Oxygen and carbon dioxide concentrations were measured frequently. The total number of analyzed air samples was more than 500 in both experiments. We used a non dispersive infra-red ADC CO_2-analyzer type SS1-mk3 and a paramagnetic Servomex O_2-analyzer type OA-570. These instruments were connected with tubing and placed in series. A small nitrogen flow controlled by a Brooks thermal mass flow controller was flushed through the tubing and instruments and caused a zero reference outputsignal (flat baseline on a recorder). Injection of 2 ml sample in the nitrogen flow just before the flow enters both instruments gives a peak on the outputsignal (voltage) of the analyzers. These signals (peaks) were recorded on a flat bed x-t recorder type Kipp en Zn. BD 41.

Comparison of the recorded peak height with the peak height of a standard gas gave an accuracy of 0.1 %. The retention time of this system is about 20 seconds and compared with the alternative GC-methods about 20 to 50 fold faster, so we were able to analyze that many samples in a short period of time. Gas samples were withdrawn through the film with needle and syringe. The puncture was sealed with adhesive tape.

Statistics:
The data were analyzed using a statistical computer program: Genstat 5 (release 2, Lawes Agricultural Trust RES). The effects of filmtype, temperature, storage time and grower were investigated, using analyses of variance (ANOVA) and the least significant difference (LSD) between means was calculated at the 5% significance level.

4. Results

Gas concentrations
Appendices 1 to 11 give of the results of the measurements of the CO_2-concentrations in graphs. Trends are shown in these figures. The highest CO_2-concentrations are found in the pe-wrapped pre-packs and the lowest in pvc-wrapped packs (fig. 1,2,6,7). Generally CO_2-levels increase with temperature (fig. 3 and 10). The effect of the grower on the CO_2-concentration is relatively small (fig. 4,5,8,9). Figure 12 shows a histogram of the CO_2-levels of the various filmtypes. Pvc gives clearly the highest rate of CO_2-diffusion (resulting in the lowest CO_2-concentration), secondly Suntec and finally pe-film.

In table 1 an overview is given from the averaged CO_2-concentrations in time (after 24h.) in the pre-packs from both experiments. There was no interaction between both experiments and the four growers. Therefore all data are averaged in time and represented by one value.

Table 1: CO_2-concentrations (%) in the pre-packs.

3 days	pe	Suntec	pvc	unwrapped
8 °C	10.6f	8.9de	6.5b	0.05a
18 °C	14.1g	10.8f	7.1c	0.05a
6 days				
8 °C	9.3e	8.3de	5.8b	0.05a
18 °C	11.5f	8.1cd	6.5b	0.05a

LSD= 1.0 $P<0.05$. Values with the same letter do not differ significantly.

For each storage time and temperature all concentrations differ significant except the difference between Suntec and pe at 6 days-8°C.
In both experiments all oxygen concentrations were below the detection limit of the used analyzer. This means that in all overwrapped pre-packs the concentration was below 0.1% O_2-concentration. Because of this effect leak packages could be detected easily. When the oxygen concentration was higher than 1% then the pre-packs were determined as leak and skipped out of statistical calculations.

Weight losses
Appended to this report are figures 13 till 22. In these figures it is shown that factors as filmtype, temperature, grower, storage time and experiment have a different effect on weight losses. Fig. 13 and 18 show that the unwrapped punnets lost up to 40% of fresh weight depending on storage time and temperature. The effect of grower is not consistent in the unwrapped pre-packs. Possibly this is caused by the way of stacking the plastic trays containing 4 punnets each in the cold stores. Two trays were placed on top of each other and this might have caused a higher relative humidity respectively a lower air velocity in the lower tray although the trays are very open. This changed microclimate effects the transpiration rate of the product.
In fig. 17 and 22 we see that there is only a minor difference between growers. Generally weight losses from pre-packed mushrooms are negligible. Only pvc-film gave clearly more weight loss than the other films, but always to a very low extend: max. 1.5% (18°C-6 days). Figure 14,15,16 and 19,20,21 give an overview of the results. In experiment 1 pe gives the lowest rate of weight loss and Suntec in experiment 2. Differences are very small.
In table 2 the results of the analysis of variances of the weight losses of both experiments are shown. There were no significant interactions between experiments and growers. Results are averaged over these factors.

Table 2: Weight losses in % in mushroom pre-packs.

3 days	pe	st	pvc	unwr.
8 °C	0.17ab	0.13a	0.42c	9.3
18 °C	0.26b	0.26b	0.80d	17.5
6 days				
8 °C	0.28b	0.25b	0.54c	12.3
18 °C	0.43c	0.54c	1.49e	33.2

LSD= 0.06 P<0.05 (Unwrapped was extended). Values with the same letter do not differ significantly.

Pe and Suntec have no significant difference in influence on weight loss at the same temperature and storage time. Pvc has a clearly significant higher water vapour transmission than the other films.

Condensation

Water condensed on the underside of the films and on the walls of the punnet. All wrapped pre-packs gave some condensation on the film. Detection of differences between factors are not determined as we have no objective measurement method. Visual inspection gave no discrimination.

Whiteness

In table 3 the results of the measurement of whiteness based on the visual inspection are shown. There were no significant interactions between the factors. Thus temperature, experiment and grower is combined to one value.

Table 3: Measurement of whiteness (visual inspection) in mushroom pre-packs wrapped with various filmtypes. (0= brown 10= white)

	pe	Suntec	pvc	unwr.	LSD
3 days	5.02b	5.90a	6.15a	4.67c	0.34
6 days	5.01a	5.41a	5.49a	4.55b	0.50

P<0.05. Values with the same letter do not differ significantly.

Whiteness measurements based on Minolta reflection measurements are given in table 4.

Table 4: Whiteness values

	pe	Suntec	pvc	unwr.	LSD
3 days	88.23a	88.35a	88.25a	83.95b	1.02
6 days	86.90a	87.09a	88.08a	83.23b	1.41

P<0.05. Values with the same letter do not differ significantly.

The discrimination of the visual inspection method is better than the Minolta reflection method, so from this moment we consider only the data of table 3. After 3 days the browning of pe-wrapped pre-packs is significant higher than that of Suntec and pvc-wrapped pre-packs. There is no

difference between pvc and Suntec. After 6 days storage there is no significant difference between all package variations only unwrapped is significant browner than the packed mushrooms. This is mainly caused by a high relatively dry air velocity along the unwrapped pre-packs. Mushrooms on the bottom of the punnets were white (whiter than overwrapped punnets) and on top they were extremely brown.

Stipe elongation

The results of the measurements of the stipe elongation are given in table 5. As there were no interactions between experiments, temperature and grower the mean values are given.

Table 5: Stipe elongation (%) of mushrooms during storage in different pre-packs.

	pe	Suntec	pvc	unwr.	LSD
3 days	4.3a	3.9a	4.3a	14.0b	1.8
6 days	9.1b	5.3a	9.6b	14.6c	2.2

P< 0.05. Values with the same letter do not differ significantly.

After 6 days the retardation of the stipe elongation of Suntec film was significant better than the other two filmtypes. At 3 days this difference is not significant yet with a probability threshold of 95% .

Cap development

Opening of the caps was inhibited in all packages. There was no difference in development stage of the cap between all overwrapped pre-packs. Percentage closed was 100%. Only the unwrapped punnets showed open caps. Table 6 shows how cap expansion was related to time and temperature.

Table 6: Cap development (%) of unwrapped mushrooms.

temp.	time	open	'gevl.'	closed
18 °C	3 days	100	0	0
	6 days	100	0	0
8 °C	3 days	26	35	39
	6 days	73	27	0

4. Discussion

Weight loss.
The internal atmosphere of the pre-pack is very rapidly modified by the fast-respiring short-lived mushrooms. It seems likely that only the internal gaseous composition of the pre-packs is responsible for the quality effects on the mushrooms since all films prevented water loss. The differences in water loss between the pre-pack variations are negligible (<0.8%). For comparison the weight loss of the unwrapped mushrooms at 8 and 18°C is 9.3 and 17.5% respectively (see table 2). This indicates that the relative humidity inside the pre-pack is saturated and independent of the film.

Gasconditions.
Comparing the unwrapped mushrooms with the wrapped mushrooms the results of this experiment support earlier studies that the development of the mushrooms can be retarded almost completely by high CO_2-concentrations and very low O_2-concentrations.
Table 1 and figure 12 show that there are significant differences in CO_2-levels between the various filmtypes. A range of CO_2-levels is established depending on storage temperature and filmtype as a result of differences in CO_2-transmission rate of the tested films. The CO_2-concentration inside is for the pvc smaller than for the Suntec which is again smaller than for the pe film wrapped around the punnets for both temperatures. This indicates that the CO_2-transport through pvc is larger than through Suntec which again is larger than through pe. Note that the CO_2-transport is dependent of the thickness of the film. The by Banken selected pvc and pe-film are 16 micron thick while the Suntec film is only 11 micron. Extrapolation of our measurements to a situation in which all films would have a thickness of 11 microns (identical to Suntec) means that the CO_2-transmission rate of the pe and pvc film should increase which subsequently result in a decrease of the equilibrium CO_2-concentration in the pre-pack. Thus, the difference in CO_2-concentration between the pvc and the Suntec film should increase. Unfortunately the interaction of the diffusion and the respiration a corresponding value for the CO_2 can not be calculated. The observed differences in the experiment in CO_2-concentration between the pe and the Suntec film can at least partly be explained by the difference in thickness. This experiment gives no clue whether the intrinsic diffusion characteristics (which are independent of the thickness) are different for the tested pe and Suntec film.

Cap expansion, stipe elongation and cap development.
Inspite of significant differences in CO_2-concentrations it seems that effects on cap expansion and on stipe elongation from these different CO_2-levels are relatively small. There was no sigificant difference in the stage of development of the cap between all overwrapped pre-packs, none of them have been opened. Only in the unwrapped punnets there were open caps present. Thus, the inhibition of the opening of the cap is an MA effect. However there is no difference between the various tested films with respect to these particular observables although these filmtypes have distinguishable MA climates.

Whiteness.

The whiteness is determined by visual inspection of a panel and by use of a Minolta reflection camera. Nichols (1973) has shown that high concentrations of carbon dioxide inside the pre-packs can accelerate brown colouration. Although there are significant differences in CO_2-concentrations in the various types of pre-packs the differences in whiteness are very small.

After 3 days, for the visual inspected mushrooms only, pe-film showed significantly (probability threshold of 95%) browner caps compared to Suntec and pvc (table 3). By reducing this probability threshold it can be seen that there is a tendency that the lower the CO_2-concentration the better the whiteness.

The difference in sensitivity between the visual inspection and the Minolta measurement can be explained by the fact that the representation of the whiteness observed via the human eye is not identical to that of the Minolta camera. For the latter the spectrum is decomposed in three characteristic values (A, B, L). In this experiment we have selected the L value as the integral measure of the whiteness spectrum of the mushrooms.

Unwrapped punnets show in spite of the absence of CO_2 more browning than the overwrapped ones (with the presence of CO_2). This agrees with the result of Burton (1987) but is in contradiction with Czapski (1986). This puzzling behavior can be explained by the fact that the browning in the open punnet is accelerated by the velocity of the relatively dry air along the open punnets compared to almost no air velocity and saturated humidity in the wrapped punnets. This is supported by the observation that mushrooms from the bottom were whiter compared to mushrooms from the top of the unwrapped punnets in our experiment. Therefor these none-controlled parameters can easily explain the non uniform result of these various reported experiments.

An explanation for the unexpected small differences in discolouration, cap expansion and stipe elongation between the tested films may be the generation of the anaerobic atmosphere. In all experiments oxygen concentrations were below 0.1%. Czapski (1986) investigated the effects of an anaerobic atmosphere by applying a nitrogen atmosphere on different quality assessments. Unfortunately, his storage temperature was 2°C and he did not combine N_2-atmosphere with a range of CO_2-concentrations simulatr to the MA-conditions in this experiment. He showed that the browning of the cap under N_2-atmosphere was much lower than under other CA-conditions, however N_2-atmosphere mushrooms (comparable to anaerobic conditions) were still browner than those from a normal atmosphere. In the nitrogen treatment he found some minor growth of the stipe but in a 10% CO_2- 2% O_2-atmosphere stipe elongation was remarkably stimulated. The elongation in the latter atmosphere was even higher compared to the growth in normal atmosphere. Murr (1975) investigated the effects of a nitrogen atmosphere in combination with 5 and 25% CO_2 at 10°C, on mushroom growth only. His results is in good agreement with Csapski. Stimulation of growth when there was some oxygen (2%) in the presence of 5% CO_2. Suppression of the growth only occured when the CO_2-concentrations were higher than 25%. Again almost complete retardation of the growth in 0% O_2 was observed. From Czapski and Murr it can be concluded that anaerobic conditions reduce the browning and the growth compared to the MA conditions with low oxygen (few percentages) and high carbon dioxide (2 - 10%). This indicates that the variation in the

observed quality parameters by varying the film type is reduced because of anaerobic conditions. Murr also found that in a N_2-atmosphere the respiration was suppressed to a very low level (15 $mgCO_2$/kg-hr). In all other O_2/CO_2-combinations including normal air the respiration was about 8-10 times higher (125 $mgCO_2$/kg-hr) at 10°C.
It can be assumed that in our experiment the respiration was suppressed to that mentioned low level in all the overwrapped punnets. This is confirmed by the fact that we detected mostly higher CO_2-concentrations in the "leak packages" compared to the air-tight packs (data not shown). Thus when some oxygen apart from diffusion was able to enter the package (creating an oxygen concentration > 1%) then the respiration was stimulated about eight-fold resulting in high CO_2-concentrations, the stipe elongation increased and also extreme water condensation on the inside of the film occured. Respiration causes not only CO_2-production but also the same amount of water is produced, which obviously condensates on the inside of the pre-packs.

Perforated films.
Furthermore we made some extra pre-packs in order to simulate the packaging method of Banken: they perforated their film in order to avoid water condensation. We overwrapped some pre-packs with Suntec and we made "cold needle" punctures in the Suntec film (5*3 punctures). During inspection we saw a lot of condensation in these packs and we measured 5% CO_2 and 15% O_2 in these packs. Whiteness was kept on a high level after 3 days storage but was relatively low after 6 days. This browning after 6 days was a result of many brown spots and blotches on places where the product and the wet film (watercondensation!) made contact. We saw no detectable effects on cap expansion but the stipe elongation was extreme and by that causing more brown spots as the product was pushed more and more against the film with watercondensation on it. It can be concluded that perforation of the film causes the opposite of what Banken and possible other wholesalers aim to do.

All mentioned observations and considerations including the perforated pre-packs make clear that the anaerobic gas composition in almost all the pre-packs has leveled the differences between various treatments. We expected that the established range of CO_2-concentrations would cause significant differences in quality assessments. This opinion was based also on recent CA-storage experiments (ATO-Peppelenbos: personal communication). Peppelenbos studied the quality effects of a CO_2-range in combination with 2% O_2, a combination with no oxygen was not involved. Especially stipe elongation seems to be very sensitive to small changes in O_2-concentrations. In table 5 is shown that stipe elongation of mushrooms out of Suntec wraps is significant lower compared to the other treatments. Possibly Suntec has a lower oxygen permeability compared to pe and pvc.
Finally we were surprised about the fact that the product can be stored obviously under excessive anaerobic conditions up to 6 days without any noticeable effect on the produce such as off-odours, microbial contamination etc. To our knowledge Sugiyama and Yang (1975) considered this anaerobiosis as possibly hazardous but this opinion was discussed by Kautter et al. (1978) and they demonstrated that the risks were slight.

6. Conclusions

- Control of the MA-conditions in overwrapped mushroom pre-packs can be determined more or less by choosing overwrapping films with appropriate diffusion characteristics for water, CO_2 and O_2. Application of different filmtypes in this experiment showed significant differences in the MA-condition. The diffusion rate of CO_2 through Linwrap LBAC (pvc) was higher compared to Suntec S H-100H. V. d. Windt pe-film showed the lowest diffusion for this gas.
- Generally the effect of storage time on quality was very strong but effects of grower and temperature were small.
- Mushrooms in the unwrapped packages developed normally. Cap expansion and stipe elongation increased with storage period and temperature. Weight losses at 18 °C were so extreme that growth of the mushrooms stopped after 3 days due to a lack of internal water. These mushrooms were shrivelled.
- Water losses from unwrapped packages were very high.
- All tested films almost completely water stopped loss from the mushrooms, Suntec S H-100H and v.d. Windt pe showed a lower water transmission rate compared to Linwrap LBAC
- In all treatments in "gastight" overwrapped pre-packs oxygen was consumed within 24 hours. Thereafter anaerobic MA-condition (<0.1%) existed in all pre-packs. Apparently the respiration (oxygen consumption) at 8°C and 18 °C is higher than the amount of diffused oxygen entering the packs.
- Suntec S H-100H is a very suitable overwrapping film for 250 g pre-packs with mushrooms. Maintenance of the whiteness is as good as compared to Linwrap LBAC and better compared to a van de Windt poly-ethylene film with a thickness of 16 micron. - Retardation of stipe elongation by Suntec S H-100H is better than that achieved by the other investigated films. There were no differences on cap expansion between the films.
- The difference in CO_2-transmission between the pe (v. d Windt) and the Suntec can not, based on these experiments, be assigned to the intrinsic diffusion characteristics (independent of the distance), because of the difference in thickness between these films.
- Perforation of the overwrapping film is not advisable as the oxygen concentration will increase and by that stimulate the respiration. This causes enhanced water condensation on the film.

Literature

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Lit. 4: Mac Canna C. and T.R. Gormley: Quality assessments of mushrooms: relationship between moisture loss, colour and toughness of harvested cultivated mushrooms, 1967.

Lit. 5: Czapski J. and J. Bakowski: Effect of storage condition on the quality of cultivated mushrooms (Agaricus bisporus (Lange) Sing.). Acta Agrobotanica, 1986, vol. 39 no. 2, 221-234.

Lit. 6: Produktschap voor Groenten en Fruit: Kwaliteitsvoorschriften voor champignons 1987.

Lit. 7: Burton K.S., C.E. Frost and R. Nichols: A combination plastic permeable film system for controlling post-harvest mushroom quality. Biotechnology Letters. 1987, vol. 9, no. 8, 529-534.

Lit. 8: Kautter D.A., T. Lilly Jr. and R. Lynt. J. food Prot. 1978, vol. 41, 120-121.

Lit. 9: Sugiyama H. and K.H. Yang. Appl. Microbiol. 1975, vol. 30, 964-969.

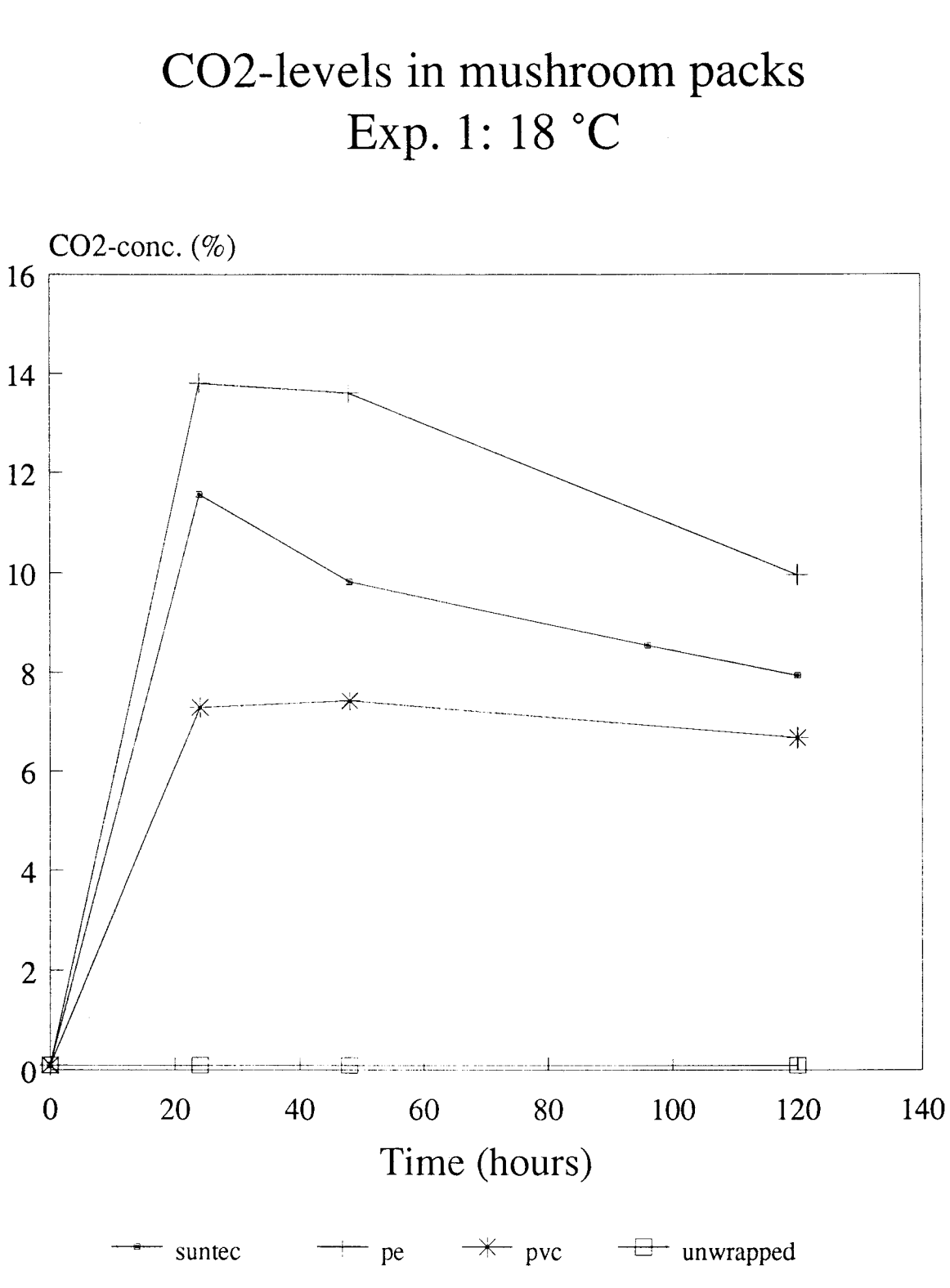
CO2-levels in mushroom packs
Exp. 1: 18 °C
CO2-conc. (%)
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time (hours)
suntec
pe
pvc
unwrapped

Figure 1

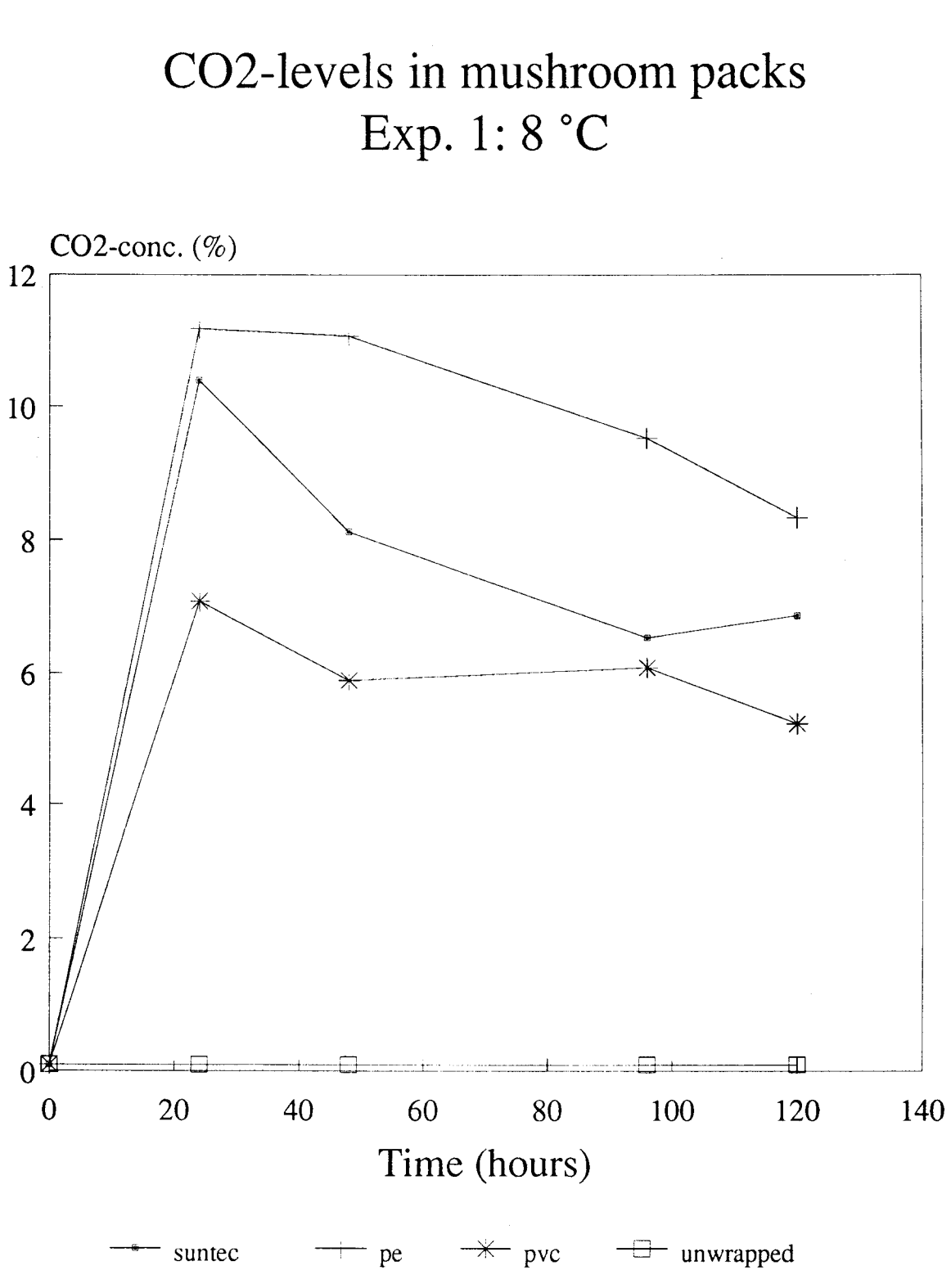
CO2-levels in mushroom packs
Exp. 1: 8 °C
CO2-conc. (%)
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time (hours)
suntec
pe
pvc
unwrapped

Figure 2

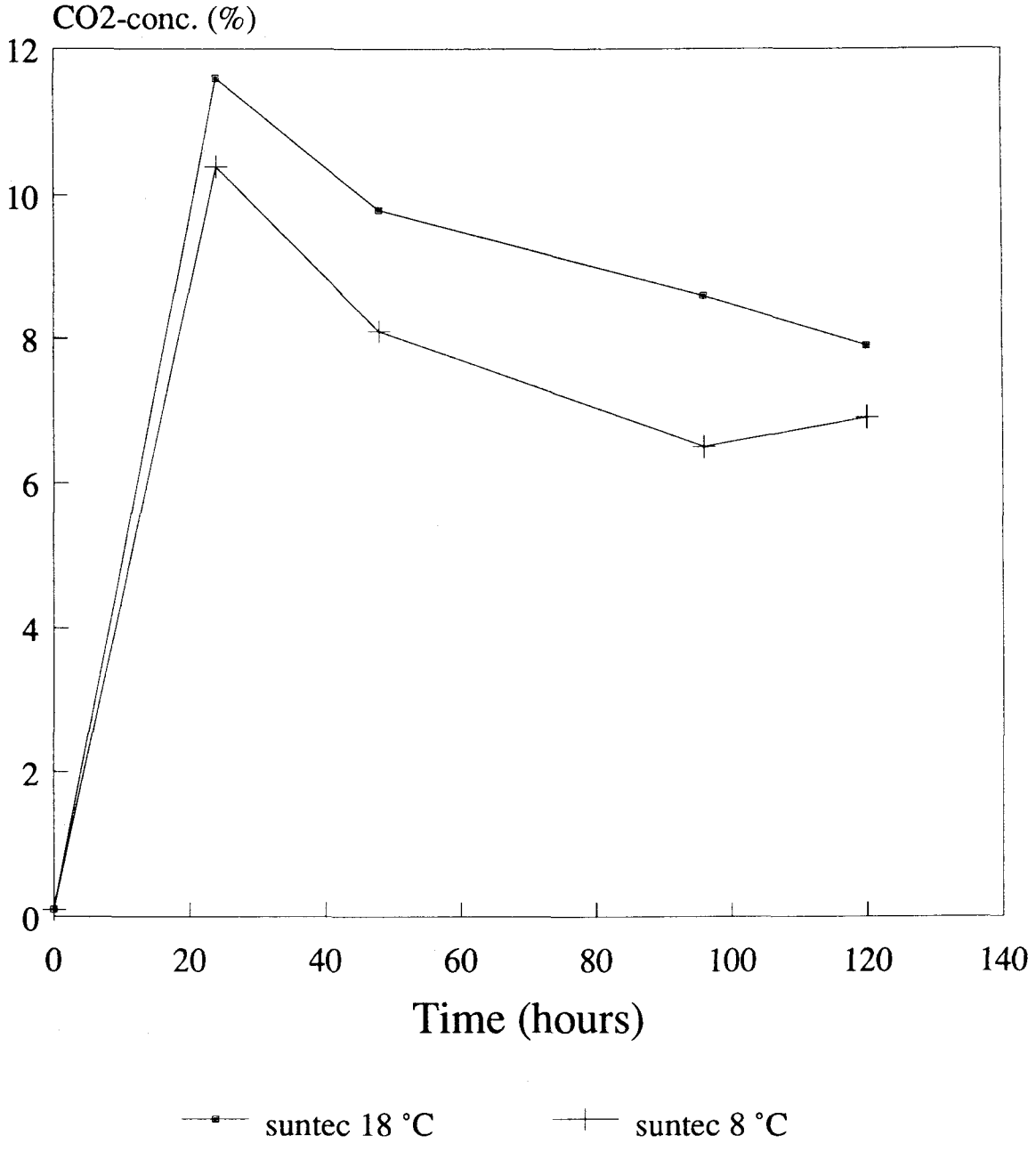
CO2-levels in mushroom packs
Exp. 1: low vs high temp.
CO2-conc. (%)
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time (hours)
suntec 18 °C
suntec 8 °C

Figure 3

CO2-levels in mushroom packs
Exp. 1: 18 °C Grower 1 vs. 2

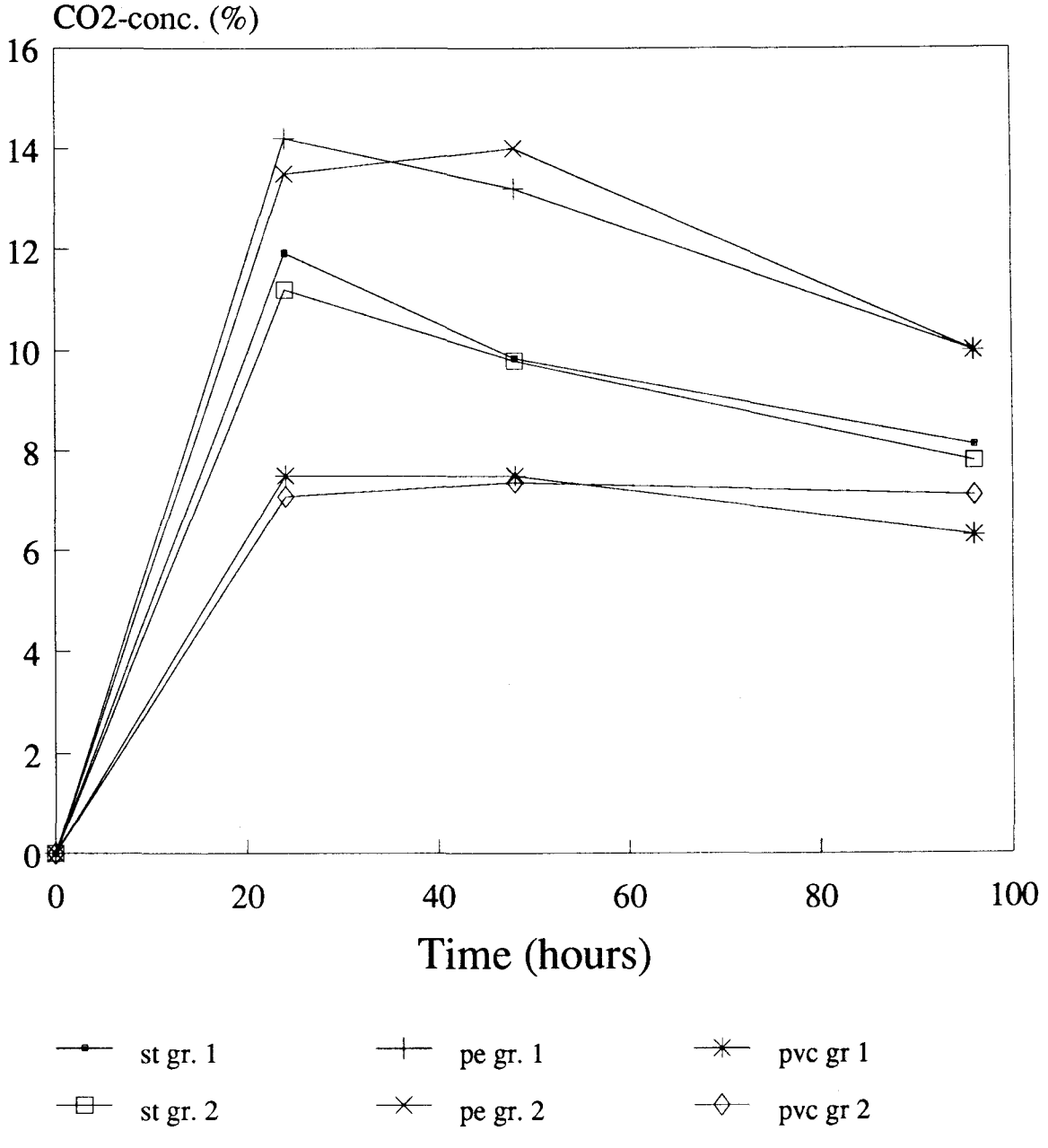

Figure 4

CO2-levels in mushroom packs
Exp. 1: 8 °C Grower 1 vs. 2

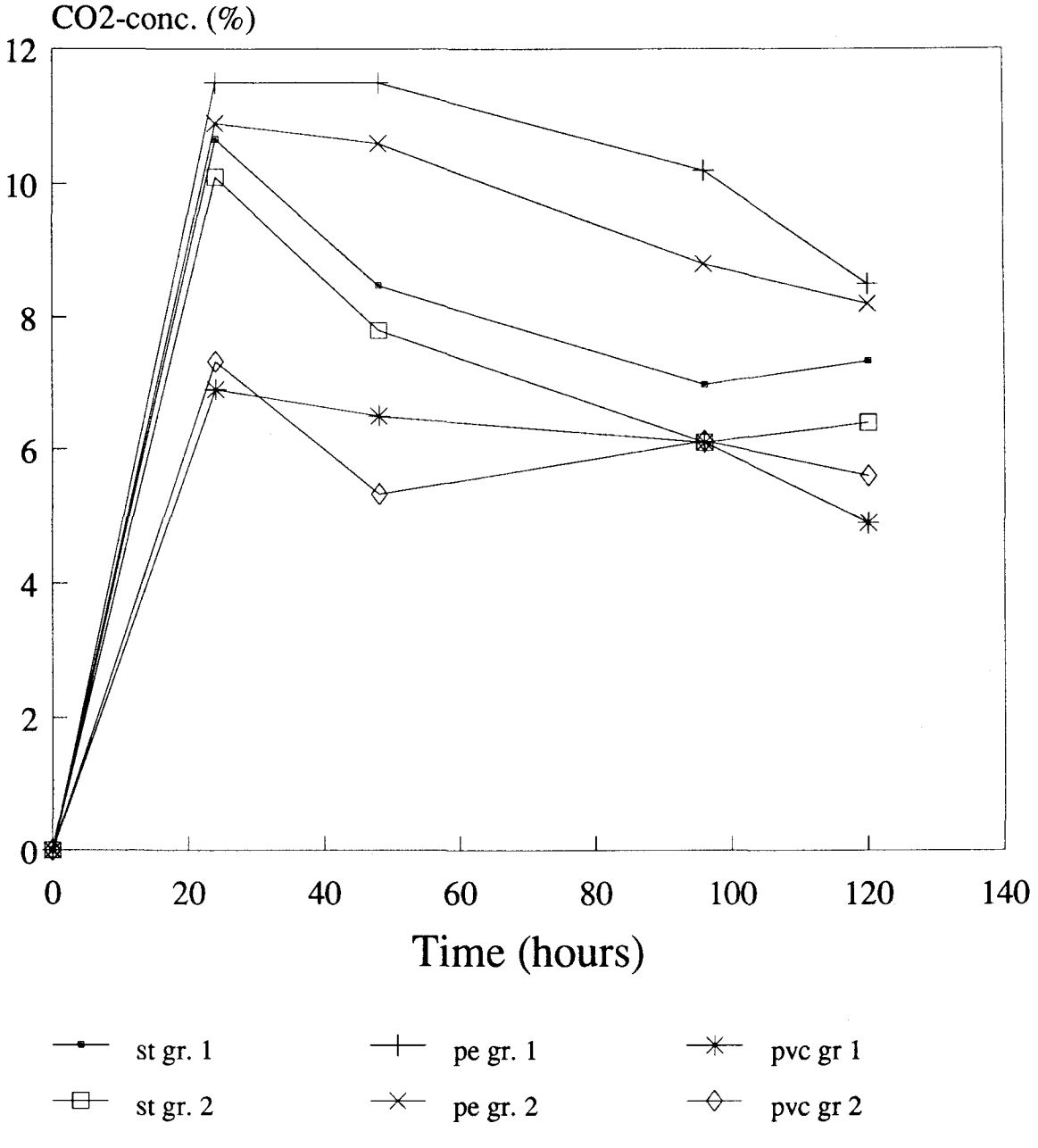

Figure 5

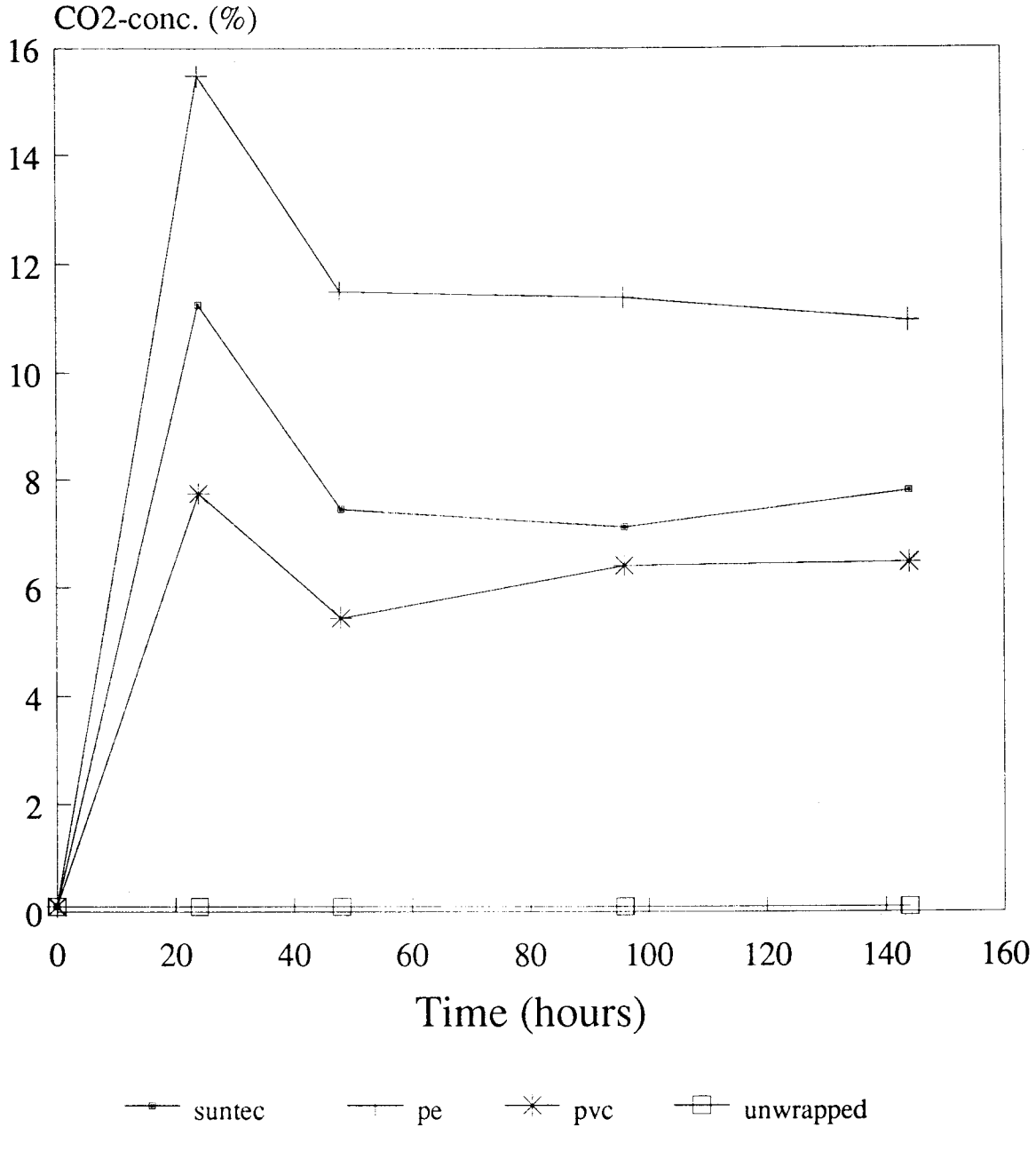
CO2-levels in mushroom packs
Exp. 2: 18 °C
CO2-conc. (%)
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
160
Time (hours)
suntec
pe
pvc
unwrapped

Figure 6

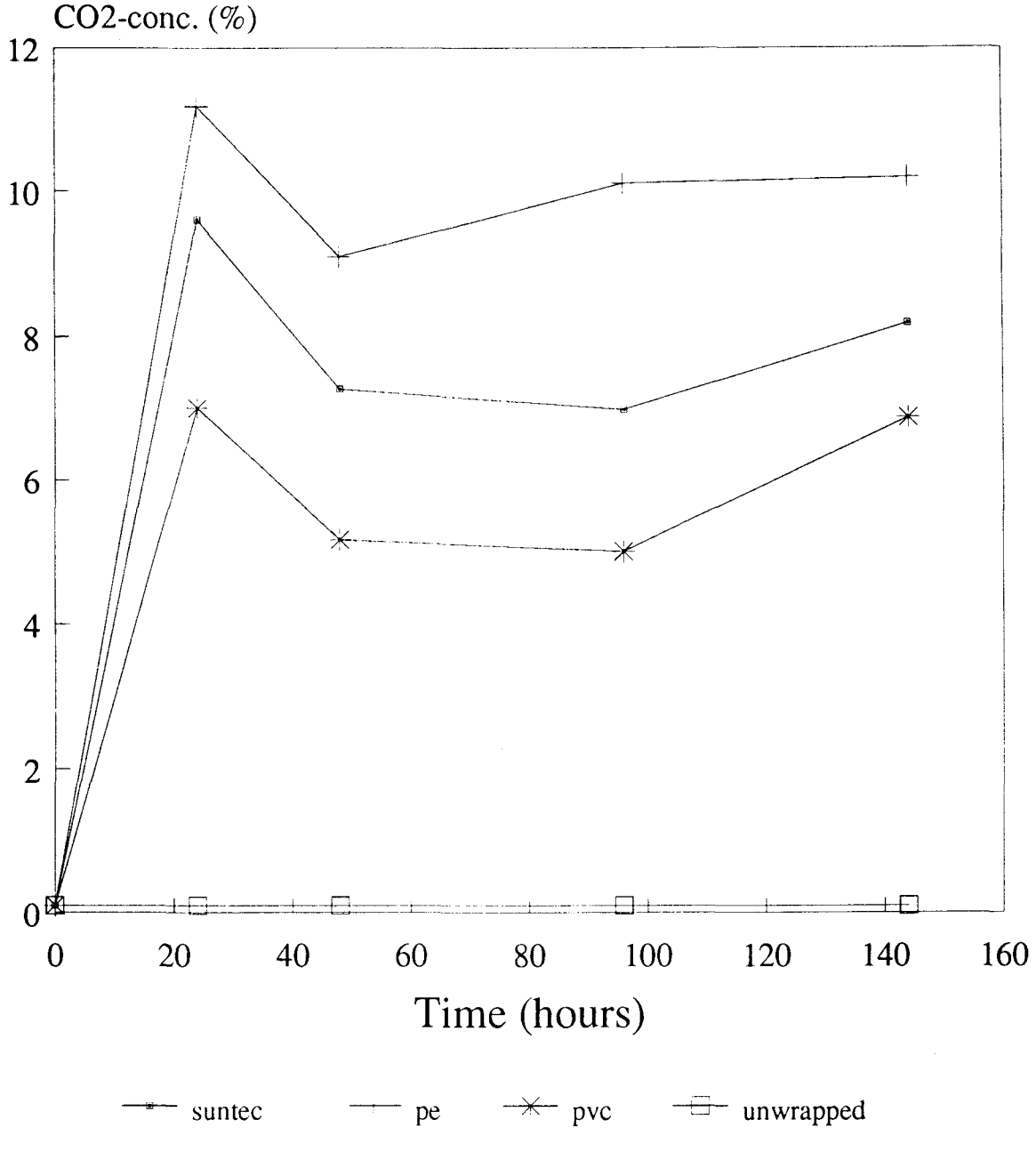
CO2-levels in mushroom packs
Exp. 2: 8 °C
CO2-conc. (%)
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
160
Time (hours)
suntec
pe
pvc
unwrapped

Figure 7

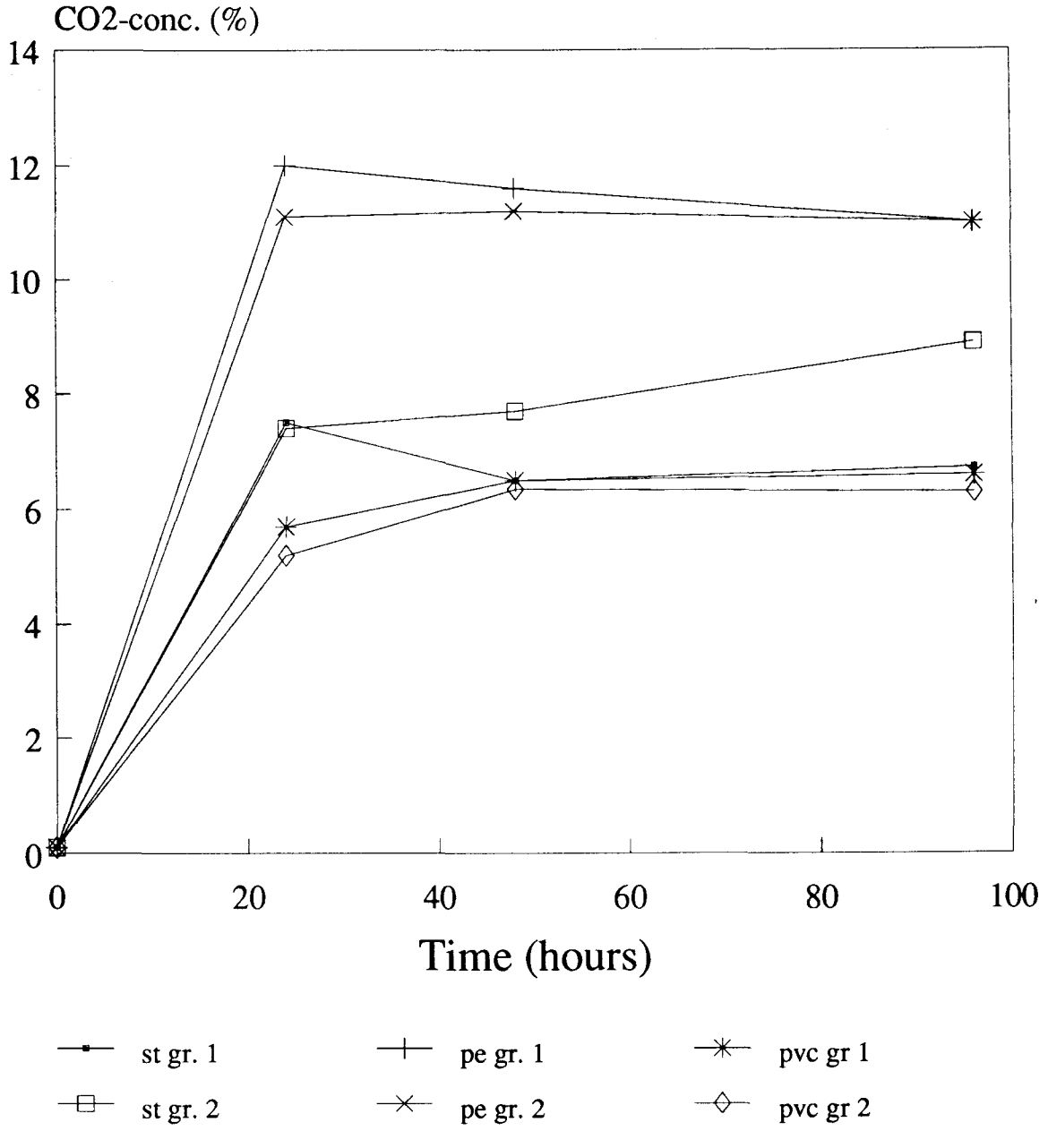
CO2-levels in mushroom packs
Exp. 2: 18 °C Grower 1 vs. 2
CO2-conc. (%)
14
12
10
8
6
4
2
0
0
20
40
60
80
100
Time (hours)
st gr. 1
st gr. 2
pe gr. 1
pe gr. 2
pvc gr 1
pvc gr 2

Figure 8

CO2-levels in mushroom packs
Exp. 2: 8 °C Grower 1 vs. 2

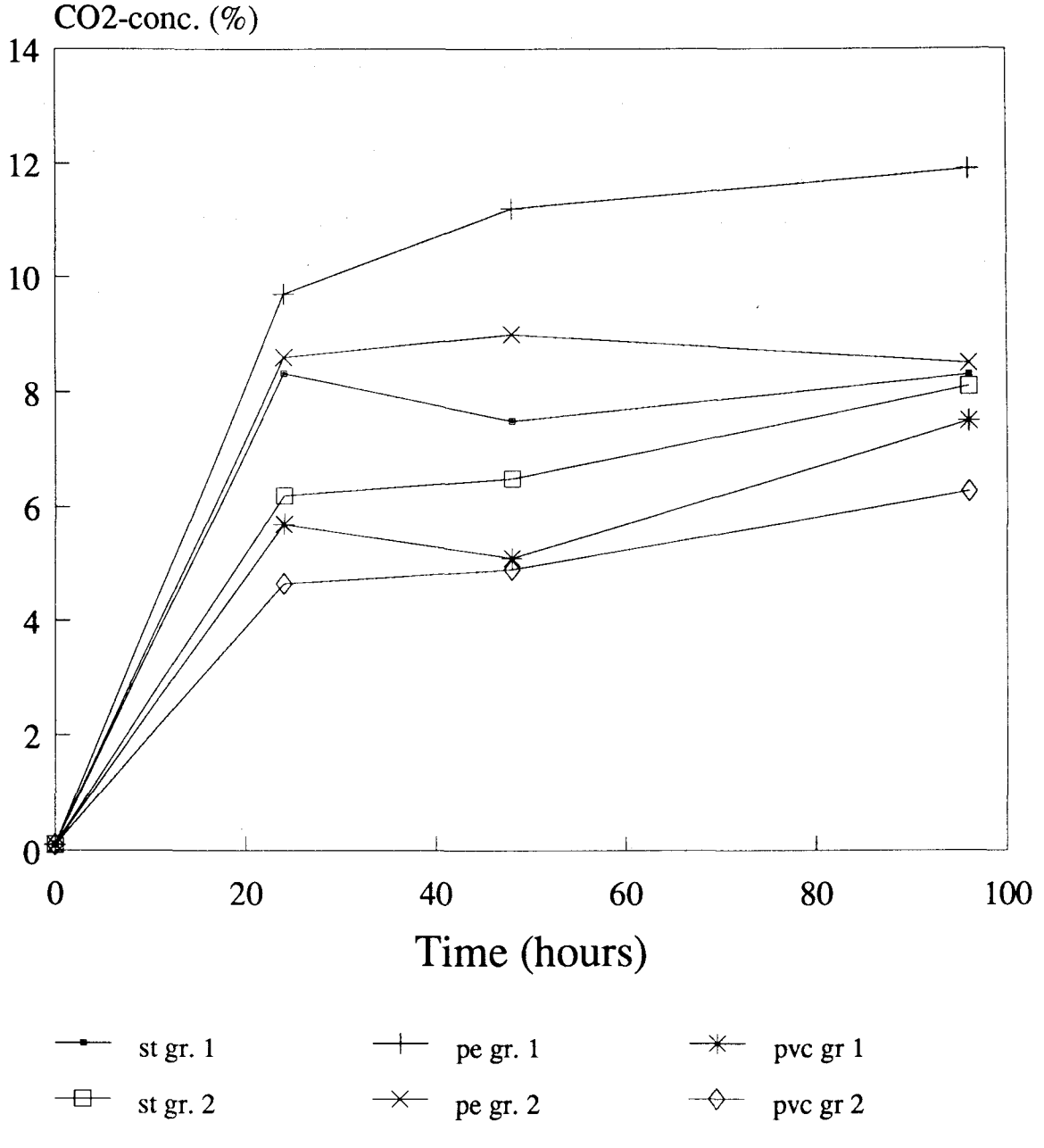

Figure 9

CO2-levels in mushroom packs
Exp. 1: low vs high temp.

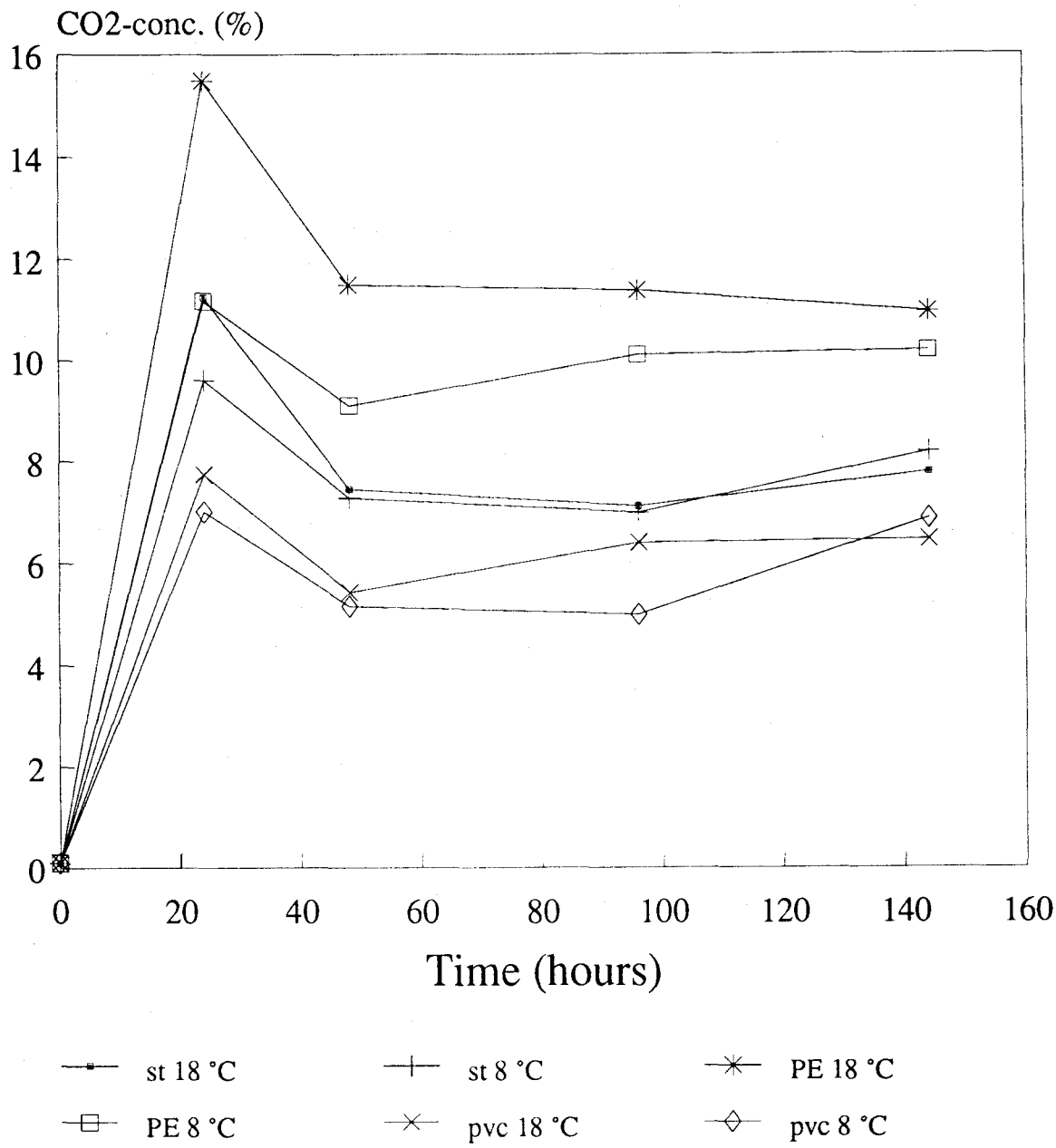

Figure 10

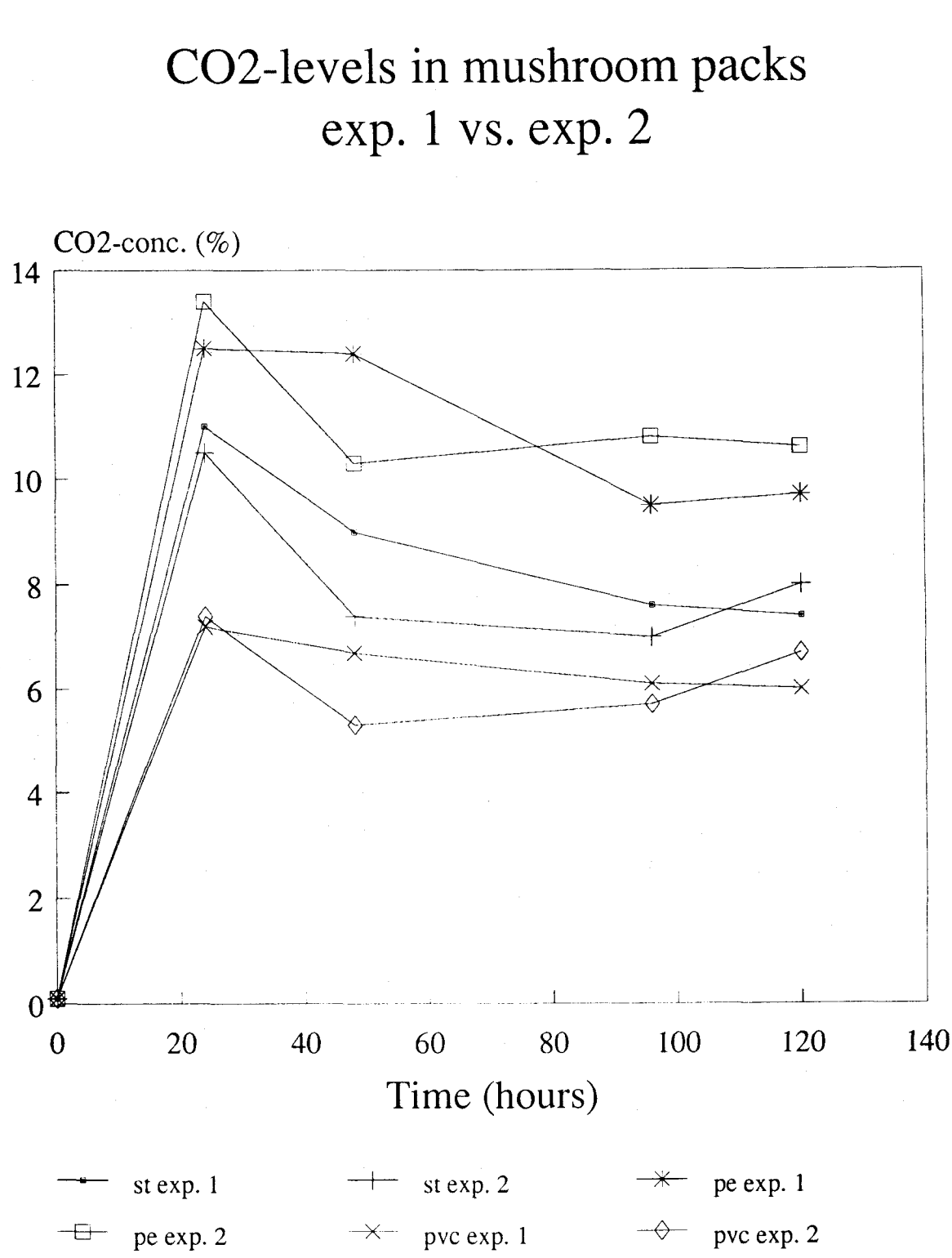
CO2-levels in mushroom packs
exp. 1 vs. exp. 2
CO2-conc. (%)
14
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time (hours)
st exp. 1
st exp. 2
pe exp. 1
pe exp. 2
pvc exp. 1
pvc exp. 2

Figure 11

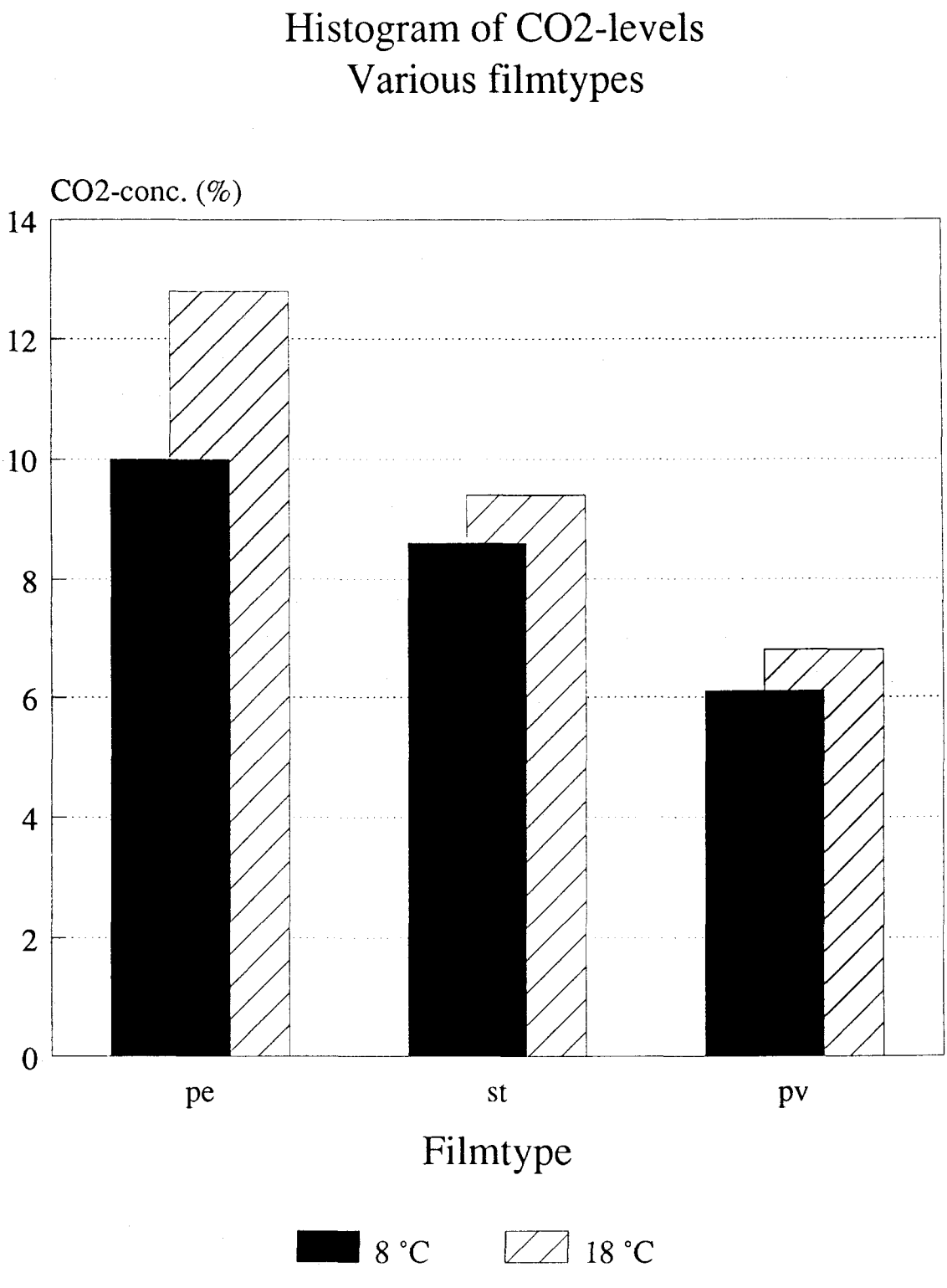
Histogram of CO2-levels
Various filmtypes
CO2-conc. (%)
14
12
10
8
6
4
2
0
pe
st
pv
Filmtype
8 °C
18 °C

Figure 12

Weight loss in mushroom packs
Exp. 1: unwrapped packs

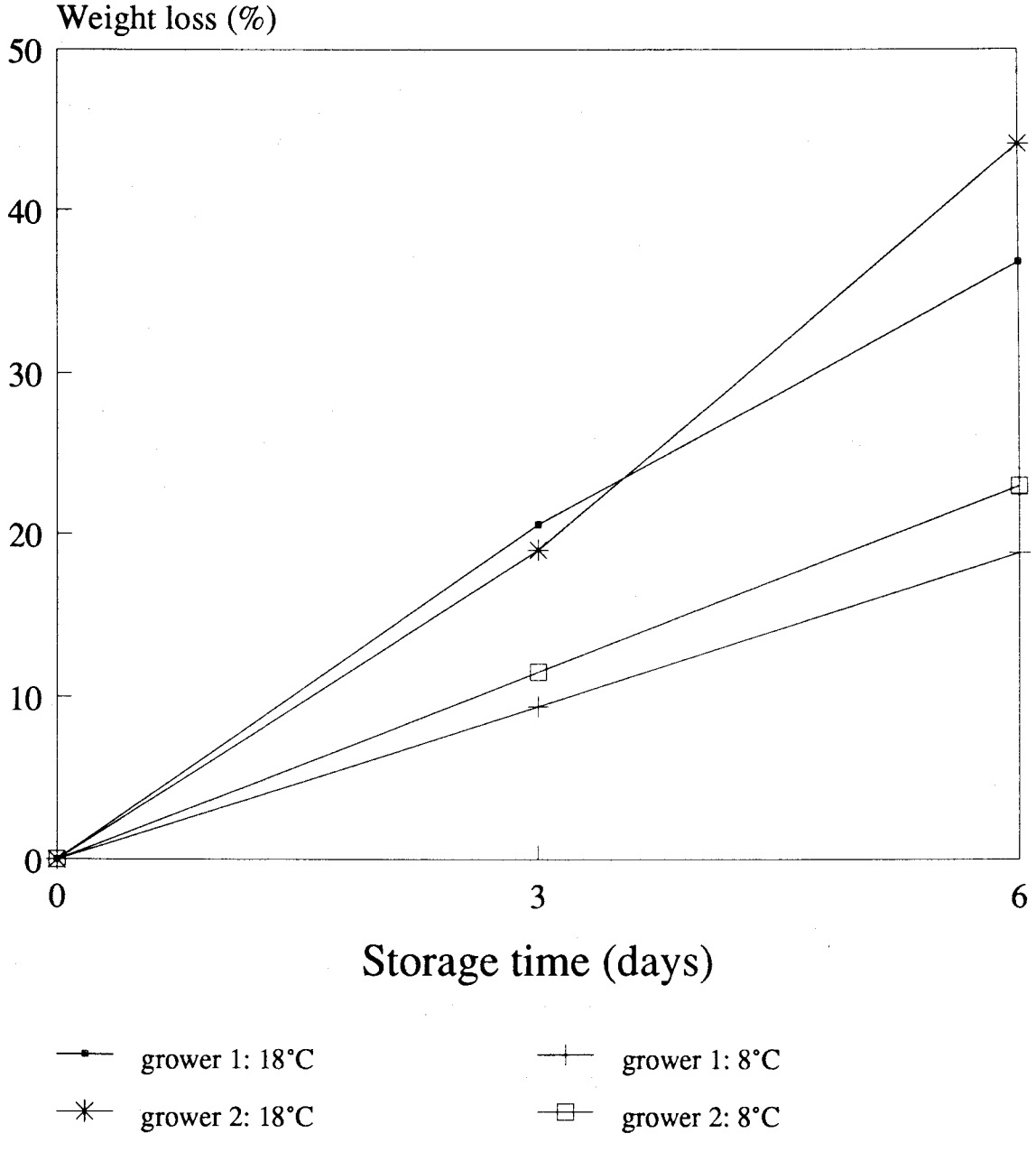

Figure 13

Weight loss in mushroom packs
Exp. 1: All films

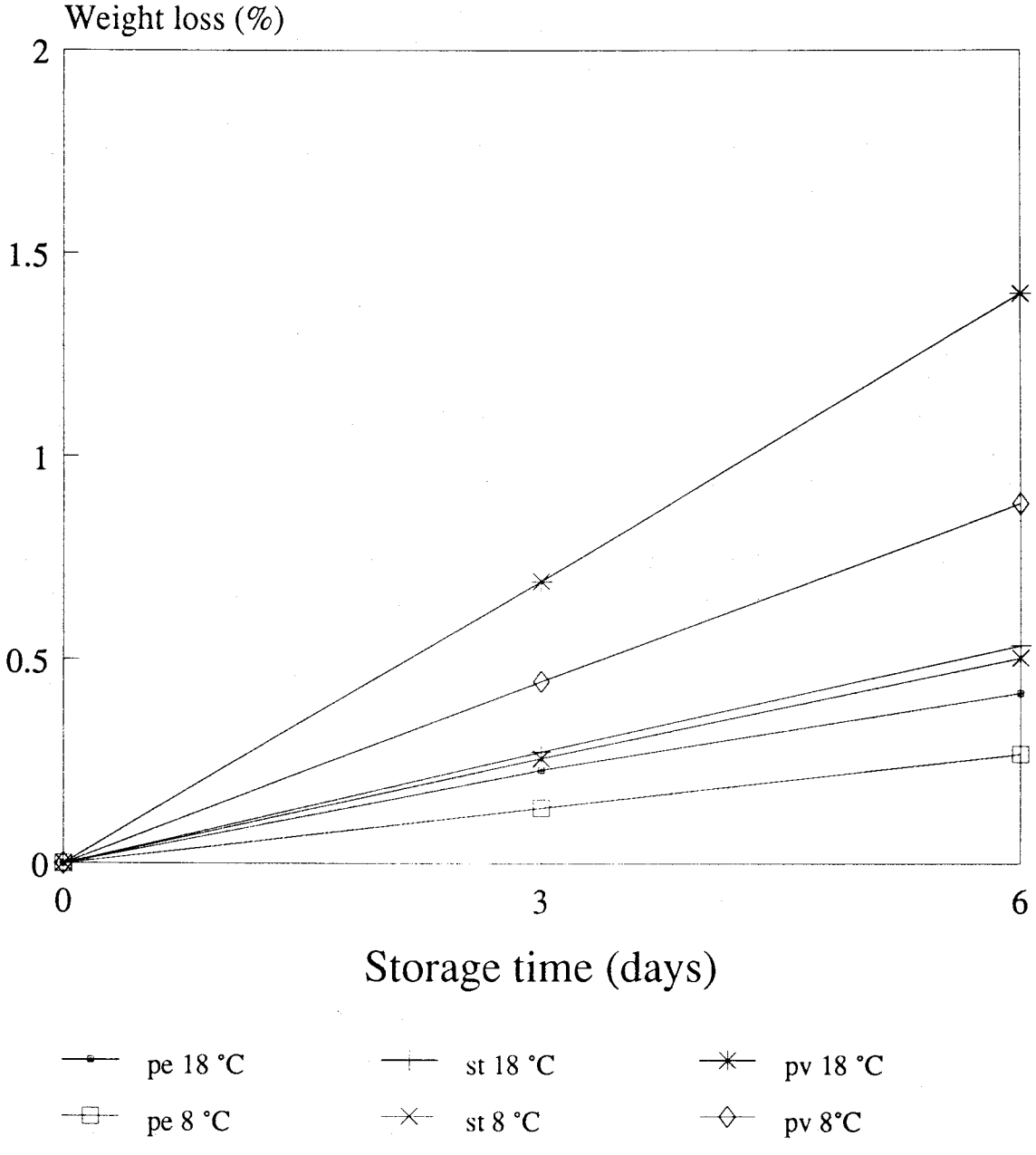

Figure 14

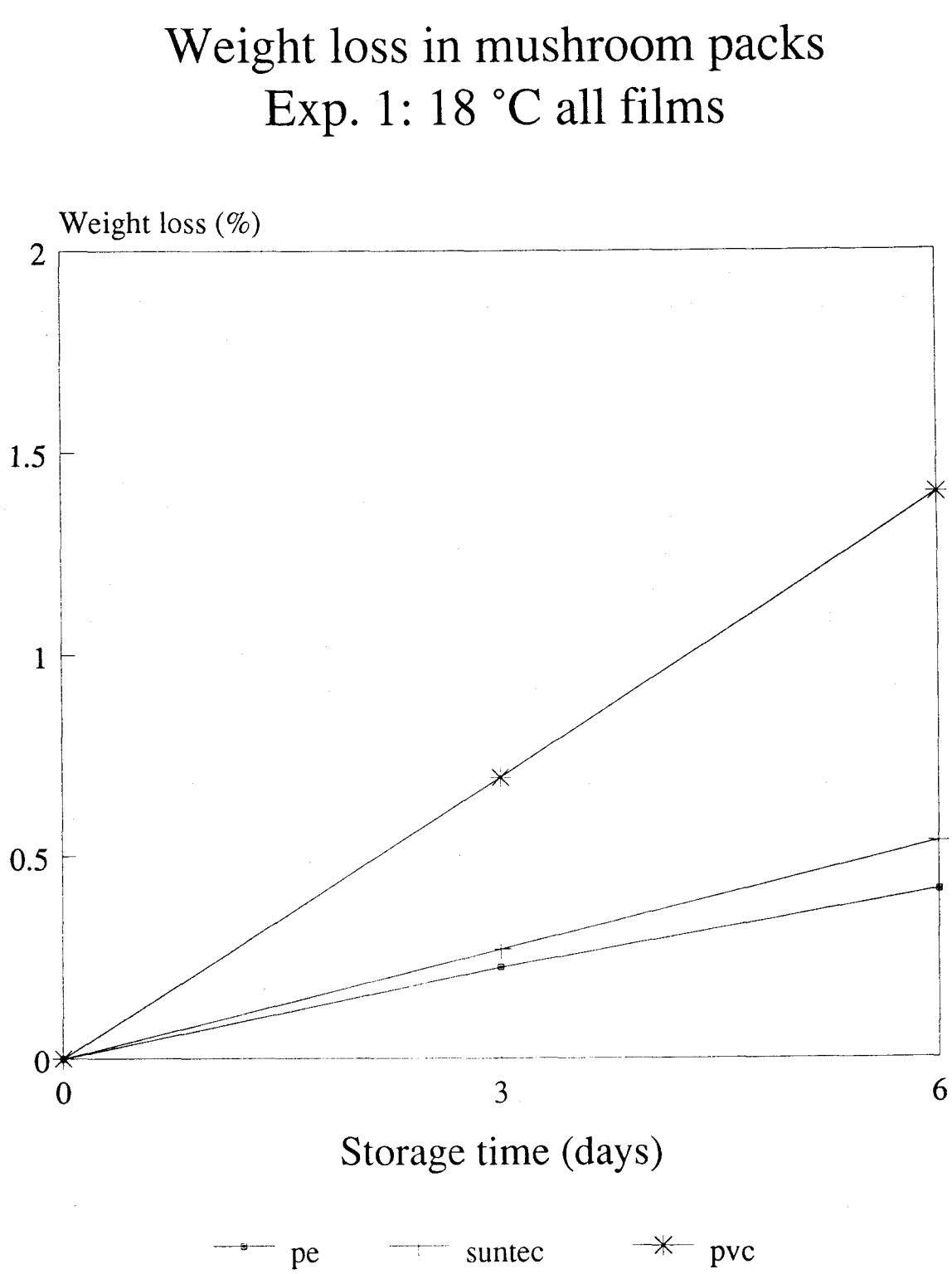
Weight loss in mushroom packs
Exp. 1: 18 °C all films
Weight loss (%)
2
1.5
1
0.5
0
0
3
6
Storage time (days)
pe
suntec
pvc

Figure 15

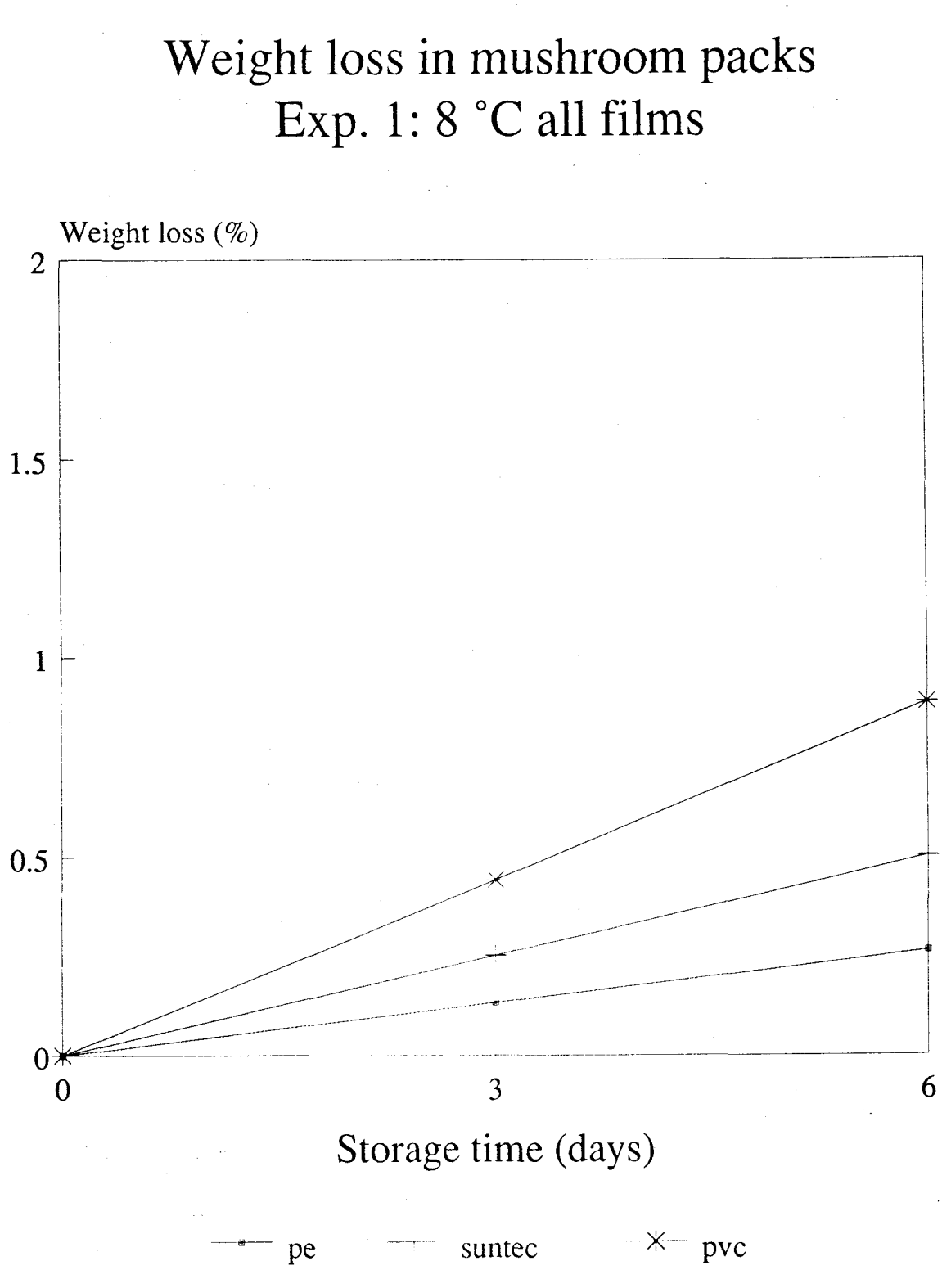
Weight loss in mushroom packs
Exp. 1: 8 °C all films
Weight loss (%)
2
1.5
1
0.5
0
0
3
6
Storage time (days)
pe
suntec
pvc

Figure 16

Weight loss in mushroom packs Exp. 1 Suntec vs. PVC 18°C

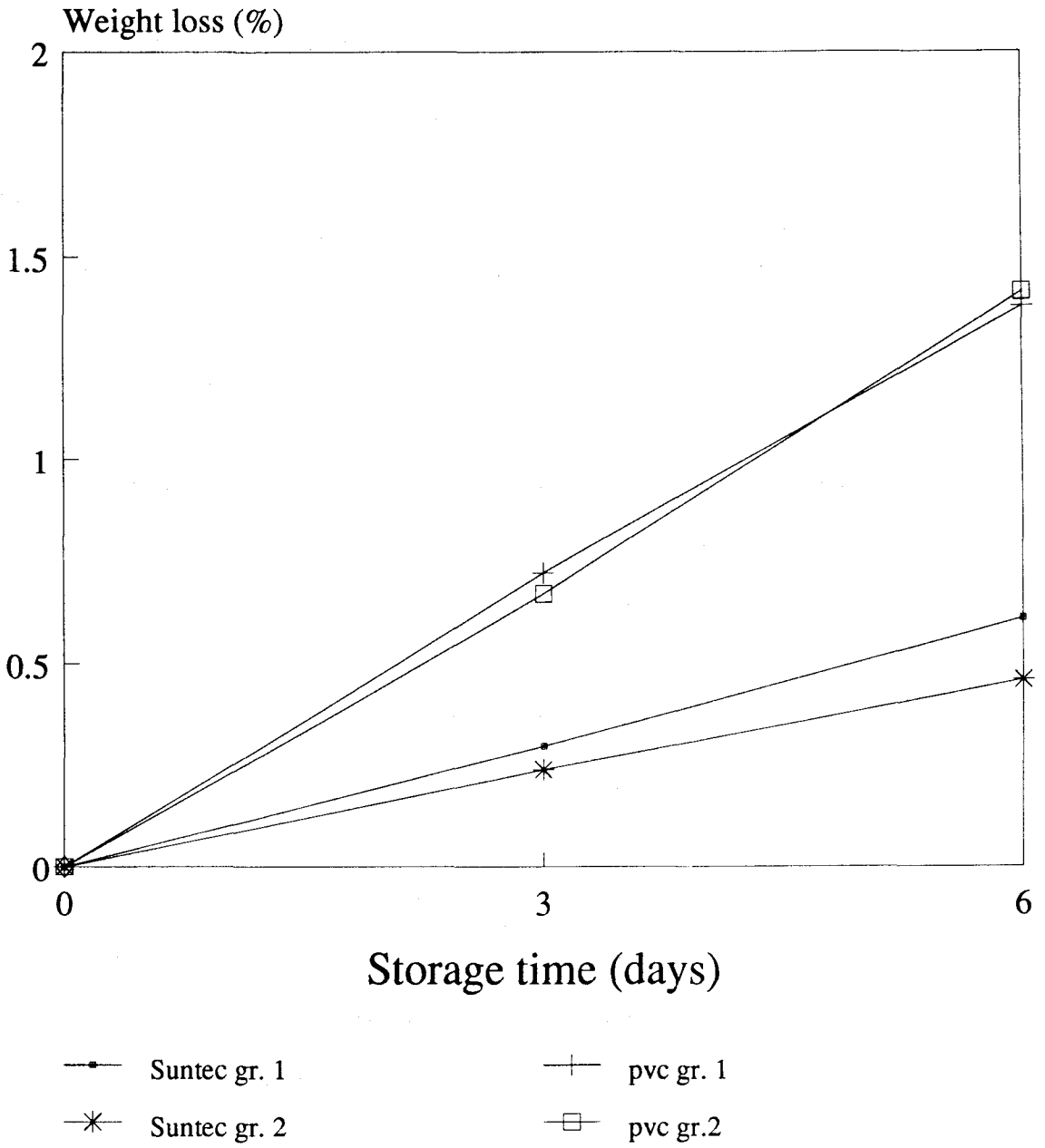

Figure 17

Weight loss in mushroom packs
Exp. 2: unwrapped packs

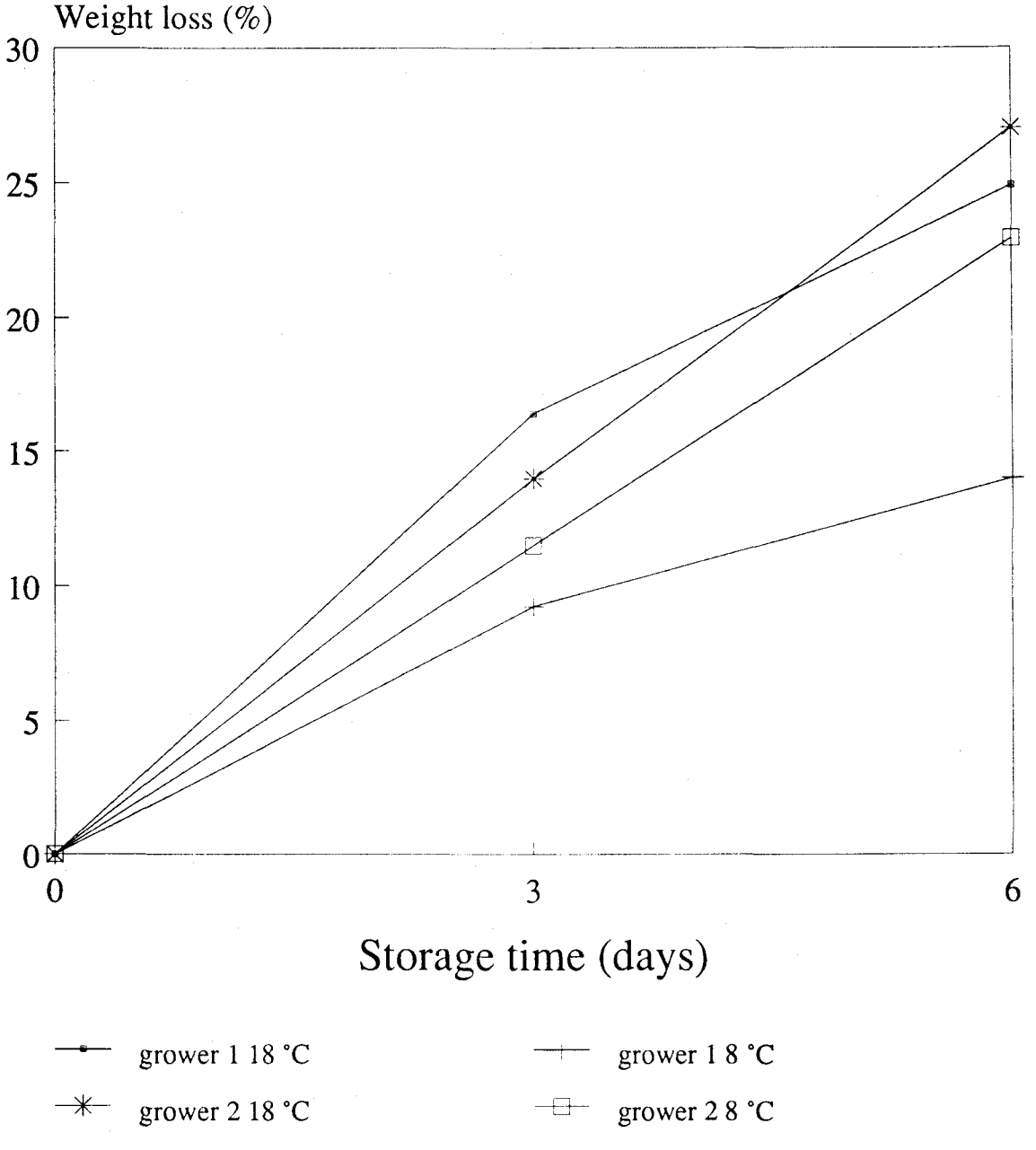

Figure 18

Weight loss in mushroom packs
Exp. 2: All treatments

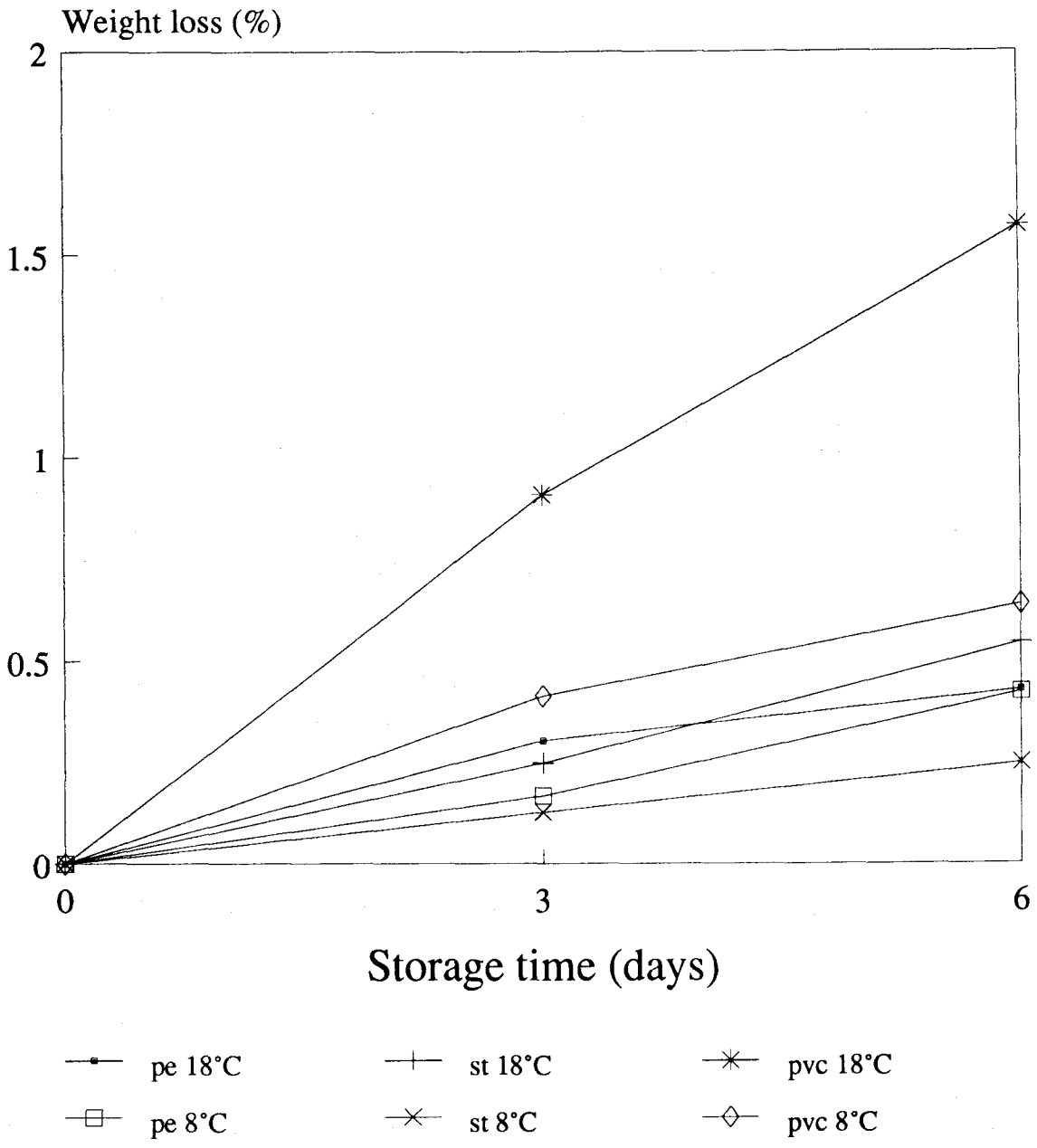

Figure 19

Weight loss in mushroom packs
Exp. 2: 18 °C

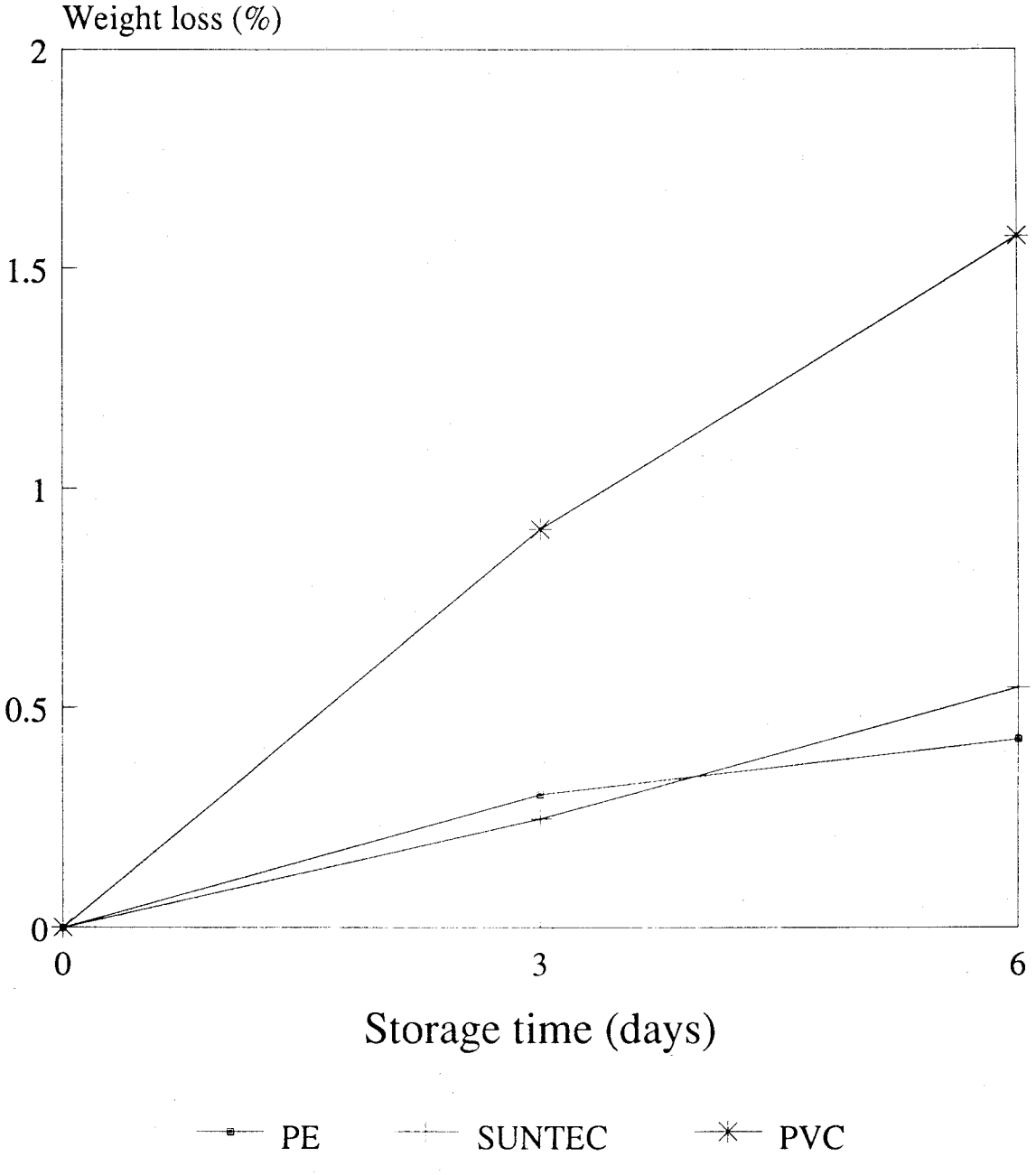

Figure 20

Weight loss in mushroom packs
Exp. 2: 8 °C

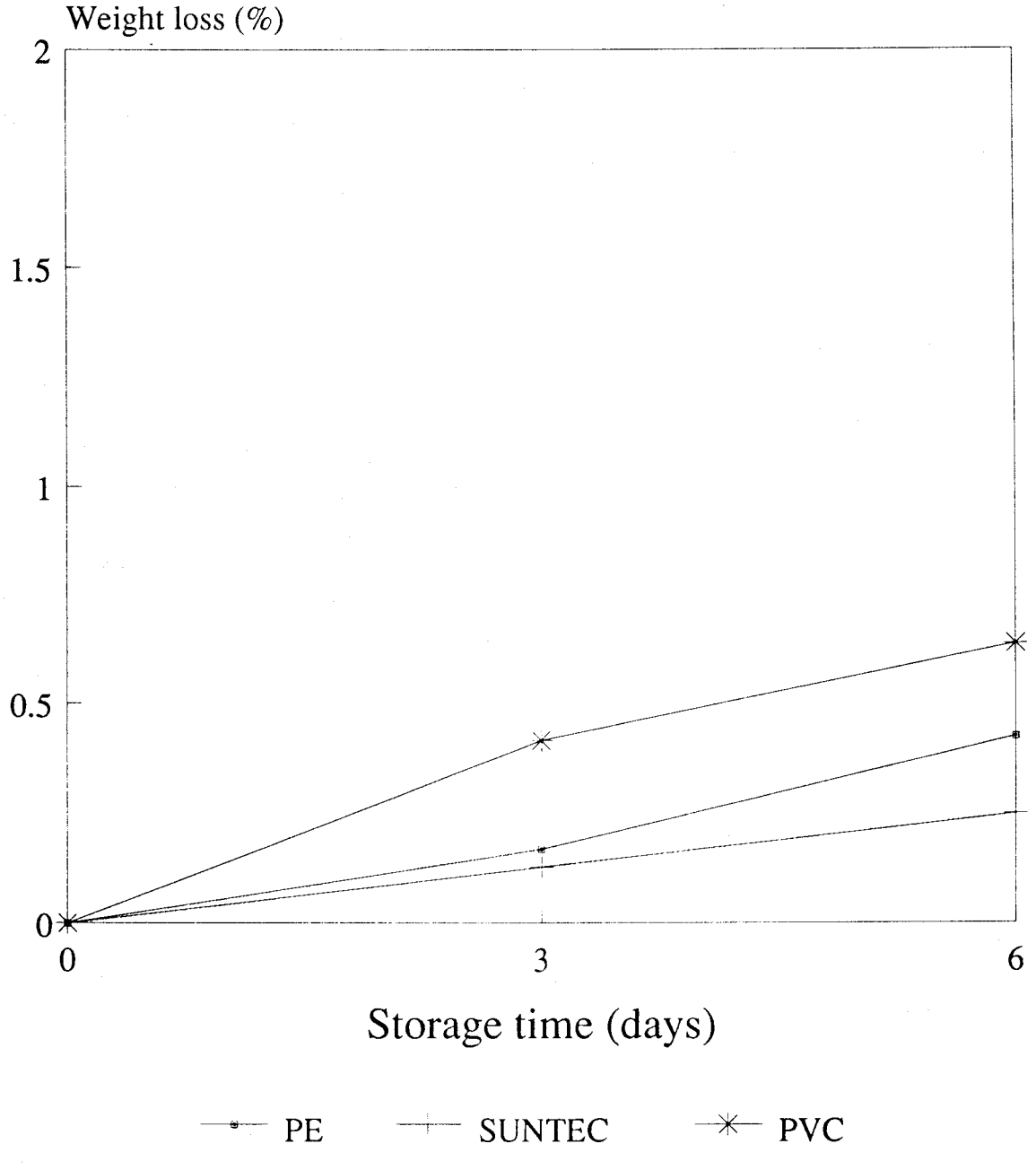

Figure 21

Weight loss in mushroom packs
Exp. 2: Grower 1 vs. grower 2

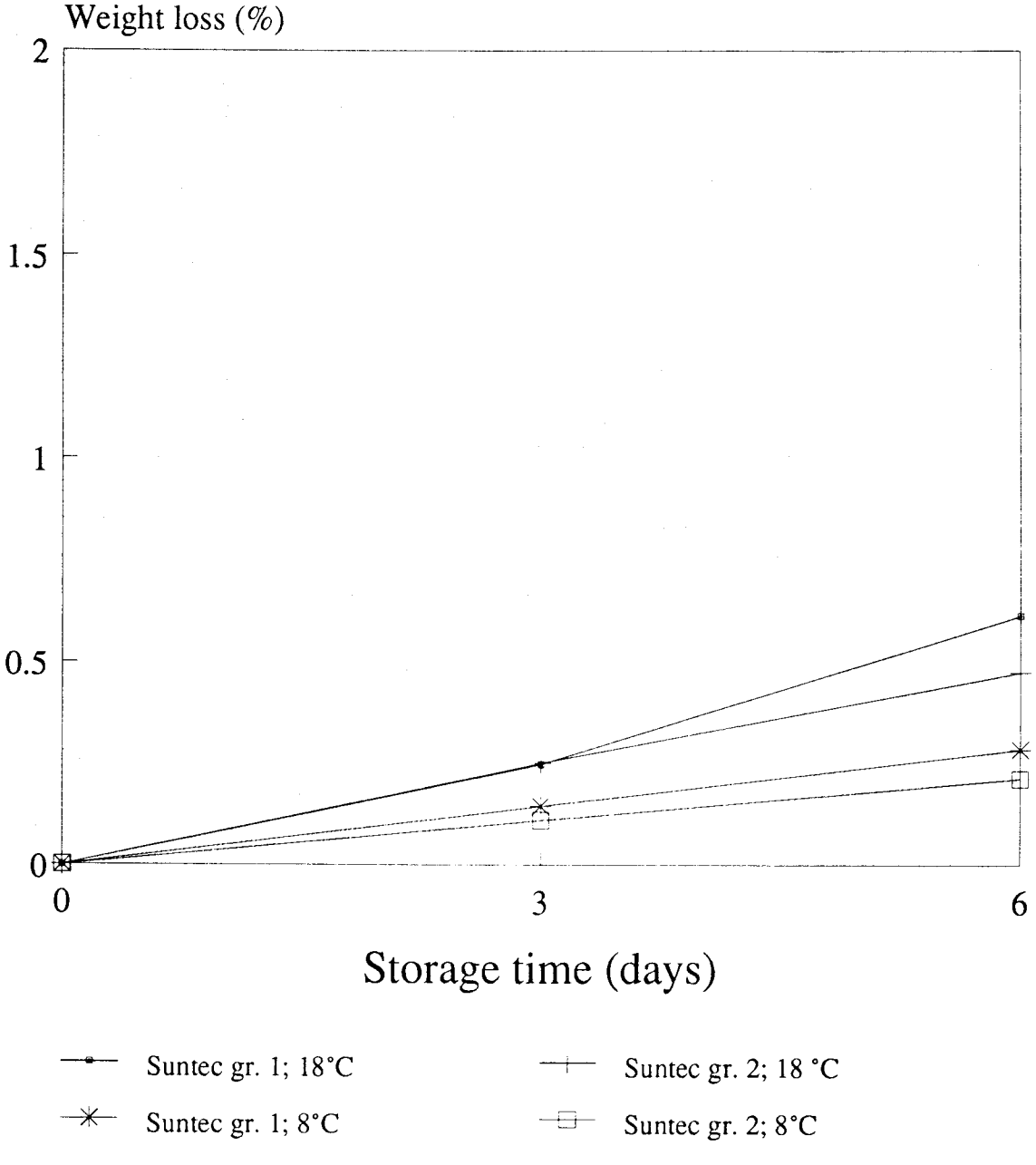

Figure 22