ATO

The effects of temperature on strawberries

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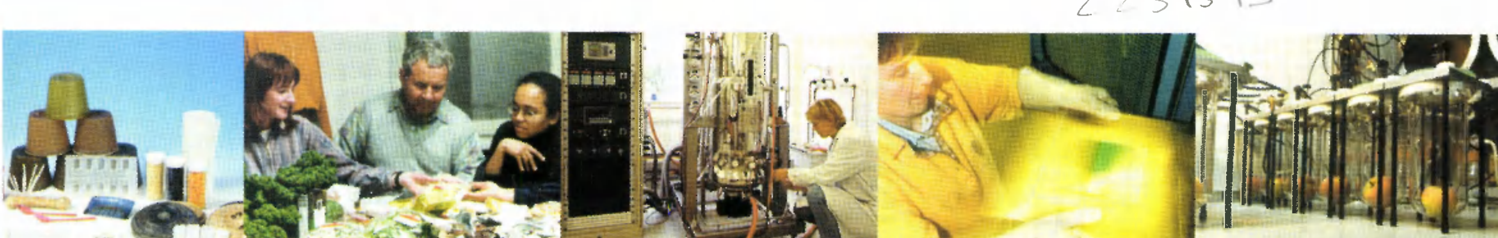


WAGENINGEN UR

Contents

0. Summary

Strawberries are popular with consumers, but marketing is limited by a short postharvest life. They are highly perishable after harvest, but quality maintenance and decay reduction is possible under special cooling and storage proceedings.
Abundant research has been done on how strawberries respond to controlled atmosphere (CA) conditions (El-Kazzaz et al, 1983; Ke et al, 1991; Smith, 1992). Benefits derived from films which produce modified atmospheres (MA) can be found in Aharoni and Barkai-Golan, 1987 and Shamaila et al, 1992. Synthetic fungicides can prevent strawberry spoilage, but are discouraged from postharvest use because they may present an oncogenic risk (National Research Council, 1987; Wilson et al, 1991). Natural volatile fungicides appear promising in controlling decay (Stadelbacher and Aharoni, 1971). There is little information concerning cooling and storage conditions on quality attributes of strawberries. The last may have great benefits for logistics and costs savings.
In this report, cooling and storage settings are tested to validate their possible contribution to prolong the postharvest storage life of strawberries. Our objective was to examine the influence of a range of temperature profiles on strawberry quality compared with the response of fruit under current storage conditions.
Elsanta strawberries were exposed to different temperature histories in order to compare product quality. Strawberry quality was assessed after cooling and during the storage period based on product decay, calyx freshness and weight loss (only in the first test). The different cooling regimes tested were based on: increase or reduction of cooling time, delay or immediate cooling and, open or closed strawberry trays.
Levels of decay were temperature profile unrelated; therefore, there were no significant treatment effects. It was analysed that fast cooling probably gives better results in a short period of time, while over a longer period of time, strawberries cooled slowly show less damage.
There is no added value for strawberry quality undergoing fast or slow cooling if there are temperature fluctuations in the remaining storage period. Temperature fluctuations substantially reduce strawberries' shelf life; fluctuations increase strawberry decay by approximately 50%.
Closed trays are bad for strawberry quality; they maximise decay.
Strawberry quality has been seen to react according to a temperature history. Strawberries decay less with high temperatures at the beginning of storage followed by low temperatures, than vice versa.

Samenvatting

Aardbeien zijn populair bij de consument, echter verkoop wordt beperkt door de korte bewaarbaarheid. Aardbeien zijn sterk bederfelijk na de oogst, handhaving van de kwaliteit en verminderen van het bederf kan worden bereikt onder speciale opslag en bewaarcondities. Er is uitgebreid onderzoek uitgevoerd naar het effect van CA en MA op de kwaliteit van aardbeien (El-Kazzaz et al., 1983; Ke et al., 1991; Smith, 1992; Aharoni and Barkai-Golan, 1987; Shamaila et al., 1992). Ook zijn er goede effecten gevonden van synthetische en natuurlijke fungicides op de bewaarbaarheid van aardbeien. (National Research Council, 1987; Wilson et al., 1991; Stadelbacher and Aharoni, 1971) Het risico van deze methodes is echter het optreden van smaakafwijkingen. Over het effect van op de kwaliteit van koeling en wisselende opslag temperaturen is echter weinig te vinden. Inzicht hierin kan wellicht tot verbeterde logistiek lijden en kosten besparingen.

De bijdrage van aangepaste koeling en bewaarcondities op de kwaliteit van aardbeien is onderzocht. *Elsanta* aardbeien zijn bewaard bij verschillende temperatuur scenario's (huidige situatie en variaties hierop) om het effect op de kwaliteit van de aardbeien vast te kunnen stellen.

De kwaliteit van de aardbeien werd beoordeeld aan de hand van het percentage rot en het uiterlijk (kroontje). Variaties ten aanzien van afkoeling en opslag die werden onderzocht zijn; verschillende afkoelsnelheden (tussen de 20 minuten en 12 uur); Direct na oogst afkoelen of 12 uur uitstel; stabiele bewaartemperatuur of wisselingen; open of gesloten pondsverpakkingen.

De gevonden percentages rot waren niet afhankelijk van de opgelegde temperatuur scenario's. Het effect van snel of langzaam afkoelen van aardbeien wordt teniet gedaan door het effect van temperatuur wisselingen later in de afzetketen. Temperatuur wisselingen in de afzet keten verminderen de houdbaarheid van aardbeien aanzienlijk. Een toename van het percentage met ± 50 % werd waargenomen. Gesloten pondsverpakkingen zijn slecht voor de kwaliteit, het percentage rot was in deze verpakkingsvorm altijd het hoogst. Bij een gelijke gemiddelde temperatuur is een keten met lage temperaturen op het eind te prefereren boven een keten met de lage temperaturen aan het begin van de keten.

1. Introduction

The strawberry is one of the most delicate and perishable fruits, being susceptible to mechanical injury, physiological deterioration, water loss and decay.
Botrytis infection is a major factor limiting the keeping quality of strawberries (Browne *et al.*, 1984; Ghaouth *et al.*, 1991; Chambroy *et al.*, 1993; Vaughn *et al.*, 1993 and Saks *et al.*, 1996). Spoilage is one of the first visible attributes the consumer is confronted with in assigning quality to strawberries. The main criterion is whether strawberries are visibly affected or not, rather than the degree of decay. Strawberry tissue may deteriorate because of botrytis infection, and *Botrytis* may develop consequent to tissue softening due to ripening.
At high temperatures, respiration increases markedly, leading to a depletion of nutrient reserves, so that fruit senescence is accelerated. Even under low temperatures and high relative humidity conditions, storage life is usually only about seven days. Prompt cooling of strawberries to near 0°C can slow down undesirable quality changes and increase the shelf life of this fruit (Boyette *et al.*, 1989; Talbot and Chau, 1991). Therefore, the importance of temperature management in maintaining the quality of strawberry is well recognised (Kader, 1992).
Humidity as well as temperature must be controlled in storage facilities. If the air inside the storage room is too dry, water will evaporate from the strawberries and they will become soft and shriveled. At a storage room temperature of 0°C, the relative humidity should be from 90 to 95 percent. Much of the water that evaporates from the fruit condenses on the inside surfaces of the room or is absorbed into packing materials.
Ripening and decay occurs rapidly at 20°C and after 8 days at this temperature, few fruit are marketable (Agriculture and Agri-Food Canada, 1997).

2. Experimental Procedures

2.1. Material

Strawberry – fresh and ripe fruit – of the cultivar *Elsanta* were used in this study. Fruit were obtained from an auction or directly from a commercial grower in The Netherlands. Fruit were in samples of 500g trays. Strawberries were exposed to different cooling profiles and high relative humidity (90-95%). The air and product temperature was measured by thermocouples and monitored using Escorts or Fieldpoint type FP-RTD 122 by National Instruments. Quality evaluations were carried out at particular moments using a minimum of four replicates.

2.2. Product Quality Evaluation

To study the quality changes in the strawberries during storage, the product was evaluated after cooling and during shelf life. The initial quality was also assessed.

A panel of, at least, two persons evaluated the quality of the strawberries. Evaluations were conducted as a blind test so the type of treatment for each tray was not known at the moment of evaluation.

The visual quality was evaluated and focussed on two parameters: decay and calyx freshness. Decay was evaluated using a score from zero to five, where zero means no decay; decay level increases up to five where strawberries show severe decay. Calyx freshness was evaluated on a scale from zero to two, zero when calyx shows good quality, one when quality is still acceptable and two if it is no longer acceptable (Figs. 1 and 2).

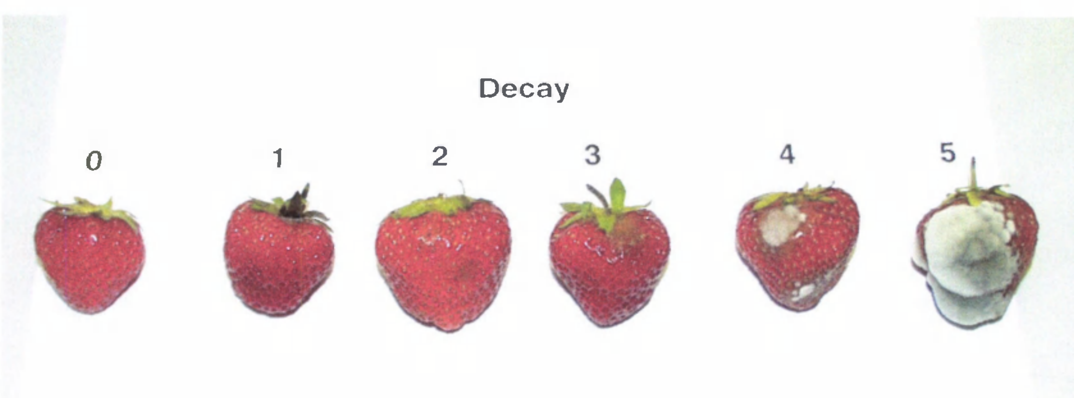


Fig. 1. Range of strawberry's decay assessed in quality inspections: zero means no decay, decay level is increasing till five where a strawberry shows severe decay.

Fig. 2. Calyx freshness scores: zero when calyx shows good quality, one when quality is still acceptable and two if it is not acceptable.

Strawberry weight loss was also calculated by comparing the weight of the product in the beginning and at the end of storage.

2.3. Statistical Analysis

The data was subjected to an analysis of variance using Genstat (release 5). LSD values were calculated at the $P \leq 0.05$ level. Correlation analyses were performed to establish the association between the subjective parameters evaluated and the objective temperature regimes.

2.4. Cooling Experiments

I Cooling Experiment:

The initial and final room temperature were equal for all: 20°C and 4°C respectively, but the cooling time was different for the three groups: 2, 6 and 12 hours (Fig. 3).

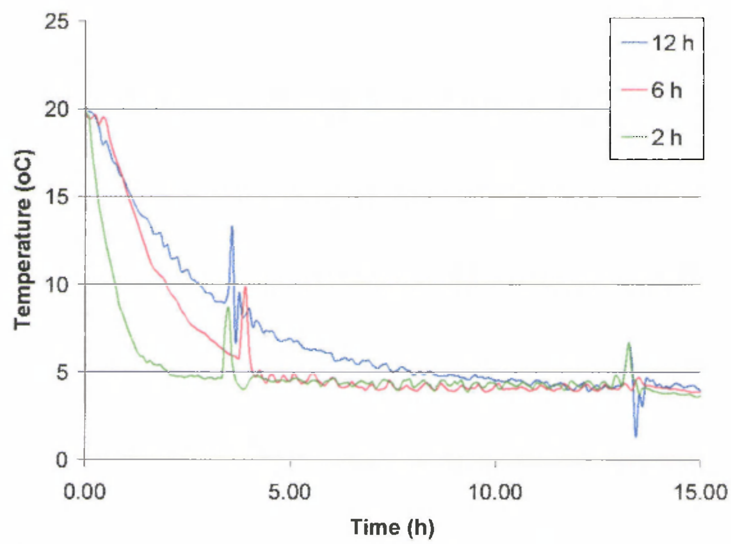


Fig. 3. I Cooling experiment: Initial temperature of 20°C and final temperature of 4°C and different cooling time: 2, 6 and 12h.

3. Results

3.1. Damage

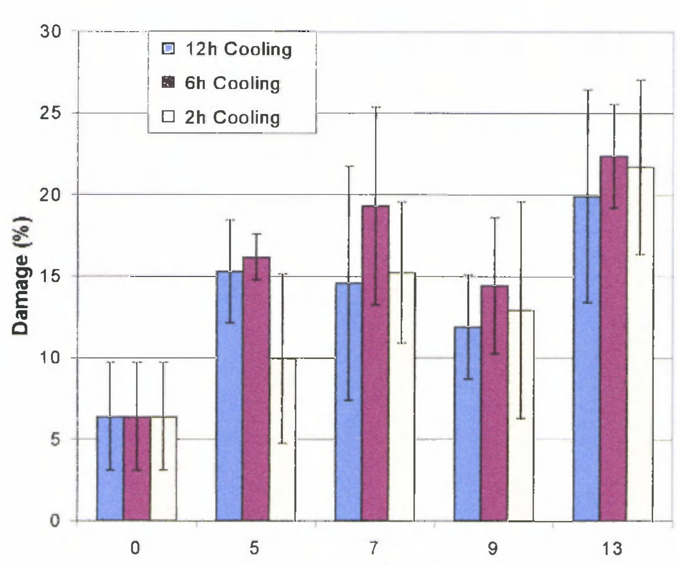


Fig. 4. Percentage of damage in time for the three different cooling times (2, 6 and 12h)

The quality in the strawberries in this experiment was evaluated based on damage, using the same scale as for decay evaluation (zero to five). This was done due to a non relevant *Botrytis* development, during the storage period of 13 days.
Cooled strawberries exhibited slight differences in quality during the storage period (Fig. 4). There was no significant difference involving the three different cooling times, thus there is, probably, no positive effect of fast cooling on strawberry quality.
The intensity of damage had higher correlation with the time of storage than with time of cooling.
The strawberries cooled in six hours showed at every evaluation moment the highest percentage of damage.

3.2. Calyx Freshness

After 9 days, the calyx from the strawberries cooled in 2h was considered not acceptable anymore; this quality was similar to the ones cooled in 6h and 12h, after 13 days.

3.3. Weight Loss

After one day as well as after one week of storage, there was no significant difference between several cooling regimes.
Weight loss after cooling and after storage period of 13 days was around 1% and 2%, respectively.

4. Conclusions

There were no significant differences in quality of the strawberries among the three different cooling times (2, 6 and 12h).
Damage was evaluated because *Botrytis* development during the storage period of 13 days was not significant enough to be taken into account.
The intensity of damage had a higher correlation with the origins (grower) and the period of storage than with the cooling time.
Cooling strawberries quickly possibly gives rise to some quality problems, especially in the long term, probably due to a big temperature differences between the skin and the strawberry pulp.

II Cooling Experiment:

The several temperature profiles in this second cooling experiment can be divided in two main groups: strawberries that were cooled to 4°C and those cooled to 8°C. The temperature profiles are shown in the following table (Table 1 and Fig. 5). Profiles with (13h) means that the cooling was delayed by 13 hours.

Table 1
Temperature profile that the strawberries were exposed to in the second cooling experiment

Temp Profile	Initial Temp (°C)	Final Temp (°C)	Cooling Time (h)	Delay Cooling (h)
4C Very Fast	4	4		0
4C Fast	20	4	2	0
4C Slow	20	4	6	0
4C Fast (13h)	20	4	2	13
4C Slow (13h)	20	4	6	13
8C Very Fast	8	8		0
8C Fast	20	8	2	0
8C Slow	20	8	6	0
8C Fast (13h)	20	8	2	13
8C Slow (13h)	20	8	6	13

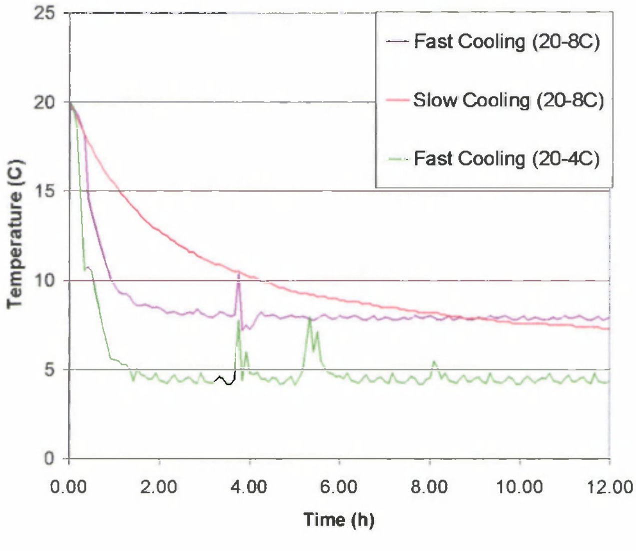


Fig. 5. Representative lines of some temperature regimes from second cooling experiment.

5. Results

5.1. Decay

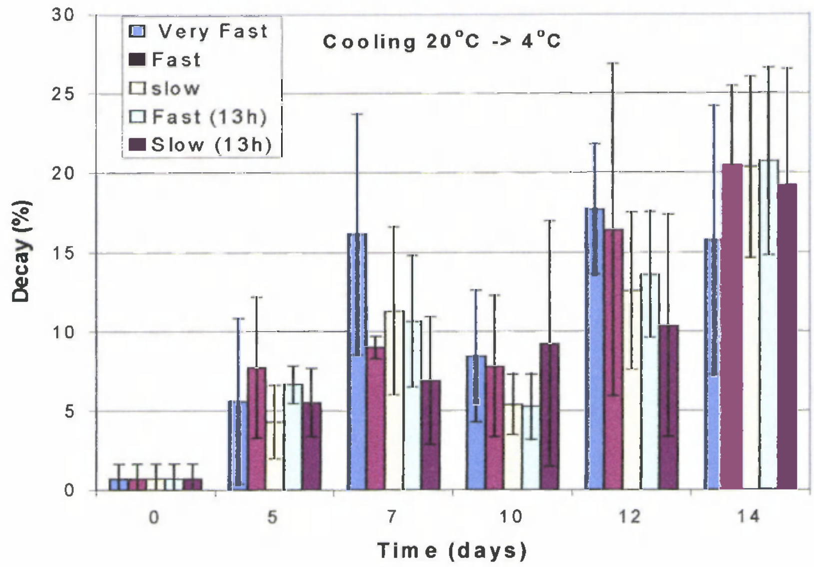


Fig. 6. Percentage of decay showed in the strawberries cooled down to 4°C accord ing to second cooling experiment.

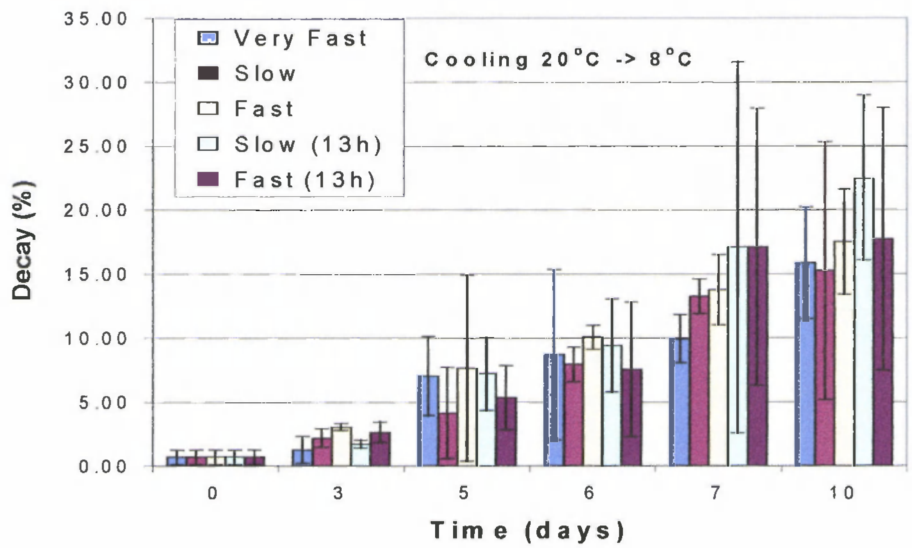
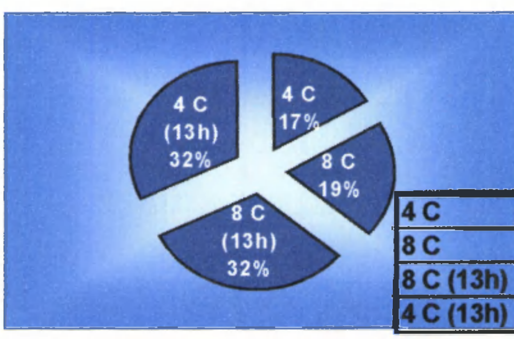


Fig. 7. Percentage of decay showed in the strawberries cooled down to 8°C according to second cooling experiment

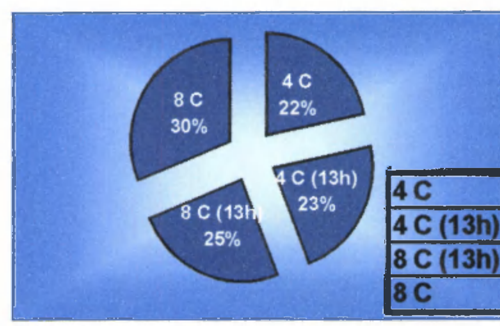
After the complete storage period, there was no difference between treatments. On the other hand, it is possible to see a trend: slow cooling when delayed 13h seems to have a different effect on strawberry quality depending on the final temperature (4 or 8°C). The strawberries that reached 4°C, cooling slowly, showed less decay (Fig. 6). On the other hand, it seems that when cooling is delayed 13 hours and the final temperature is higher (8°C), this has a negative effect on strawberry quality (Fig. 7).
The strawberries exposed to very fast cooling, especially the ones cooled to a lower temperature (4°C) showed the highest percentage of decay. Strawberries cooled very fast to 8°C showed the lowest percentage of decay, also at the end of the storage period (10 days),

5.2. Weight Loss



	Weight (g)
4 C	3.0
8 C	3.5
8 C (13h)	5.7
4 C (13h)	5.8

Fig. 8. Relative weight loss percentages after cooling in the strawberries cooled immediately and the ones that had cooling delayed.



	Weight (g)
4 C	13.4
4 C (13h)	14.1
8 C (13h)	15.3
8 C	19.3

Fig. 9. Strawberries relative weight loss percentages during storage period after immediate or delay cooling

Based on averages weight loss of strawberries, cooled fast and slow, relative percentages of weight loss were calculated and are represented in the previous charts (Fig. 8 and 9).
In order to check the influence of delay or prompt cooling on weight loss, percentages were determined considering the total weight loss, during cooling or during storage, as hundred percent. The relative percentage of weight loss in each type of treatment was obtained based on the absolute weight loss, in grams, shown in the chart table, for each treatment and relative to the total absolute weight loss from all treatments. (Ex: 18g was the total weight loss during the cooling period in all treatments, so the 3g that strawberries cooled immediately to 4°C lost correspond to 17% of the total weight loss).

Strawberries cooled immediately, independently of the final temperature (4 or 8°C) lost more weight during storage than during cooling itself: Strawberries cooled down immediately to 8°C lost 30% of relative weight during the storage period and after the cooling period itself, this was 19%. In absolute values, strawberries immediately cooled to 8°C lost 3.5g during cooling and 19.3g during storage period. The opposite happened with the strawberries cooled down after 13 hours (delayed cooling). Strawberries lost more during cooling than during storage period: Strawberries cooled after thirteen hours to 8°C had 32% relative weight loss after cooling and 25% after storage period. In absolute data, strawberries that had cooling postponed 13 hours lost 5.7g during cooling and 15.3g during storage.

6. Conclusions

Slow cooling seems to prevent decay, independently of the final cooling temperature, besides slow cooling to 8°C when delayed thirteen hours.
There is a big advantage in working with lower cooling and storage temperatures. Strawberries that reached 4°C had a lower percentage of decay compared with the ones that reached 8°C. Strawberries cooled to 4°C presented a percentage of decay between 10 and 18% and a higher percentage was revealed when cooled to 8°C (between 15 and 23%).
Very fast cooling, using a low temperature (4°C), seems to have no positive effect on quality compared with the other cooling speeds.
In terms of weight loss, it was possible to conclude that delayed cooling reduces substantially the percentage of marketable fruit.

III Cooling Experiment:

This third cooling experiment was a logistic simulation. Strawberries were exposed to several temperature profiles that are shown in the following table (Table 2 and Fig. 10).

Table 2
Temperature profile that strawberries were exposed to during the third cooling experiment

Temp Profile	**Initial Temp (°C)**	**Final Temp (°C)**	**Cooling T (°C)/t (h)**	**Closing T(°C)/t (h)**	**Closing moment**	**Temp abuse T(°C)/t (h)**
Steady 8°C/ Open	8	8				
Slow Cooling/ Closed before	12	10	4 / 6	16 / 0.7	Before cooling	12 / 3 18 / 3
Slow Cooling/ Closed after	12	10	4 / 6	16 / 0.7	After cooling	12 / 3 18 / 3
Fast Cooling/ Closed before	12	10	4 / 2	16 / 0.7	Before cooling	12 / 3 18 / 3
Slow Cooling/ Open	12	10	4 / 6			12 / 3 18 / 3

The initial temperature was 12°C for 7 hours, the time it took for the cooling room to be filled with strawberries.
The trays of strawberries that were stored in a steady temperature (8°C) were always open as well as some trays that were slowly cooled down.
All temperature profiles, besides the steady temperature (8°C), were under some temperature abuses, simulating logistics temperature abuses, such as, 12°C for 3 hours before the trays are closed, and 3 hours at 18°C simulating strawberries being placed in the expedition room before transportation. Besides these temperature abuses, the strawberries with closed trays also had temperature abuse during closing which took 40 minutes (16°C) in this simulation (Fig.10). The room temperature during cooling was adjusted in order to let the fruit reach the final cooling temperature (4°C) in 6 hours.

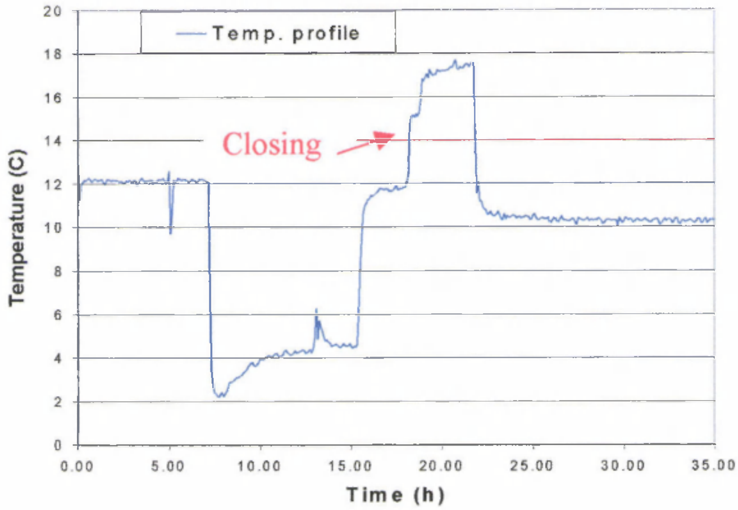


Fig. 10. One temperature profile – Slow cooling / closing after cooling, from third cooling experiment.

7. Results

7.1. Decay

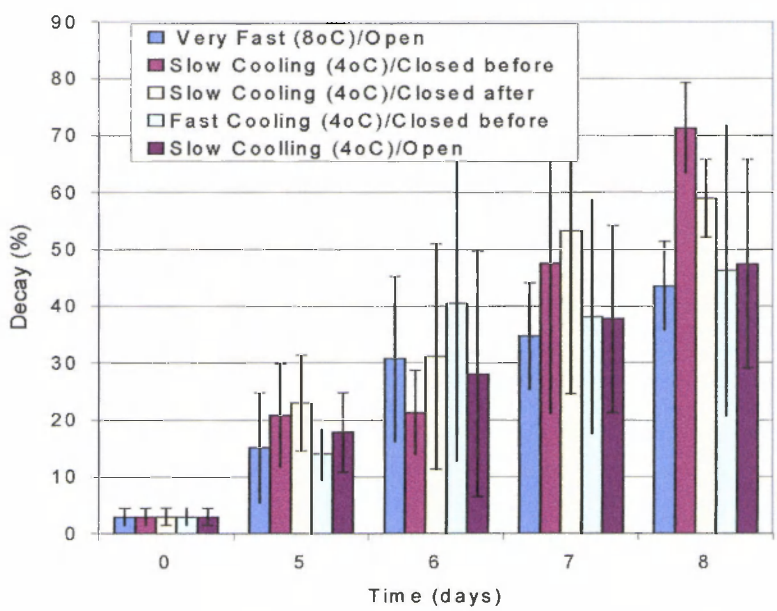


Fig. 11. Strawberries quality in terms of percentage of decay when exposed to several temperature regimes accordingly to third cooling regime.

There were no significant differences among the different treatments studied in this III cooling experiment.
In the end of the storage period (8 days), strawberry decay was very high, especially for strawberries cooled down slowly whose trays were closed before cooling (Fig. 11). These strawberries exhibited the highest percentage of decay (71%). The lowest percentage of decay was for the strawberries that were cooled very fast to 8°C with open trays (44%).

8. Conclusions

During storage, strawberries that have undergone fast cooling had less decay than strawberries under slow cooling. There is no added value in strawberry quality doing fast or slow cooling if there are temperature fluctuations during distribution. Compared with the steady temperature (8°C), after storage of 8 days, this showed less decay than the ones that were cooled down to lower temperatures and were exposed to temperature fluctuations in the remaining storage period.
Closing trays had negative effect on strawberry quality; this maximises strawberry decay especially if it is done before cooling as could be seen after a storage period of 8 days. Temperature fluctuations reduce substantially strawberry shelf life (50% more decay).

IV Cooling Experiment:

In this fourth cooling experiment, *Elsanta* strawberries packed in PA 120 films were exposed to different treatments in order to compare spoilage of the product.
The strawberries were divided into five different storage regimes (Fig. 12) (Martins, 2001).
Regime I - 8°C (9 days)
Regime II - 4°C (4days) ->12°C (5days)
Regime III - 12°C (4days) -> 4°C (5days)
Regime IV - 4°C (2days) ->12°C (2days) ->4°C (2days) ->12°C (3days)
Regime V - 12°C (2days) -> 4°C (2days) -> 12°C (2days) -> 4°C (3days)

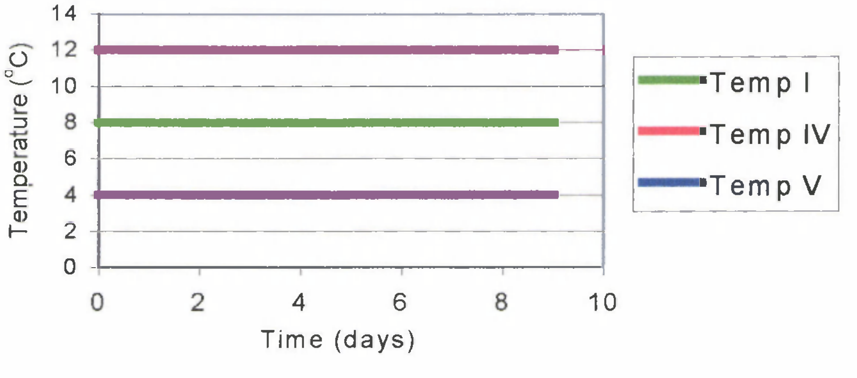


Fig. 12.Temperature fluctuations for some different regimes (I, IV and V).

9. Results

9.1. Decay

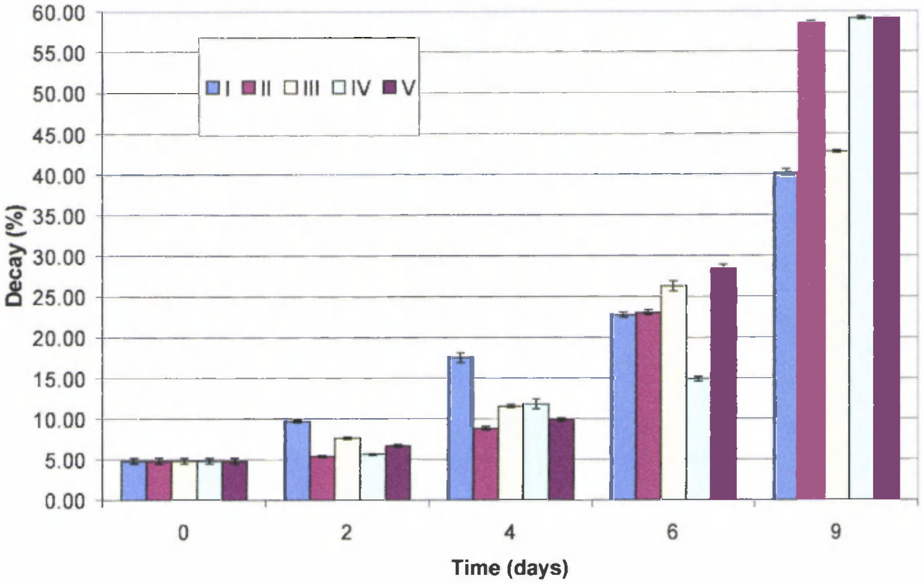


Fig. 13. Percentage of decay shown in the strawberries in the five diverse evaluation moments, (initial evaluation, after 2, 4, 6 and 9 days of storage) at different temperatures according to the different temperature regimes.

Accordingly to the chart (Fig. 13):
After two days: Regime II and IV (low temperature) had the same percentage of decay, without considerable differences: 5% and 6%, respectively. Regime V, III and I (high temperature) showed a high percentage of decay: 7%, 8% and 10% decay, respectively.

After four days: Regime II and V were not significantly different and showed the lowest percentage of decay with 9% and 10%, respectively.
Regimes III and IV were also not significantly different from each other; both regimes had 12% decay.
Regime I was the one which showed high decay (18%).

After six days: Regime IV was significantly different from the other regimes, showing less percentage of decay (15%).
There were no significant differences between Regime II and Regime I; both have 23% decay.
Regime III was significantly different from all other regimes as well as Regime V showing 26% and 28% respectively.

After nine days: Regime I was significantly different showing less percentage of decay (40%). Followed by Regime III with 43%. There were no significant differences between Regime II, IV and V, with 58%, 59% and 59% respectively.

Table 3
Overview of strawberry quality in different temperatures.
Quality symbols are comparative information for each day separately.

Time (days)	Temperature	Quality	Temperature Regime
2	Low (4 °C)	+ +	II & IV
	Constant (8 °C)	-	I
	High (12 °C)	+ -	III & V
4	Low (4 °C)	+ +	II & V
	Constant (8 °C)	-	I
	High (12 °C)	+ -	III & IV
6	Low (4 °C)	-	III
		+ +	IV
	Constant (8 °C)	+ -	I
	High (12 °C)	+ -	II
		-	V
9	Low (4 °C)	+ -	III
		-	V
	Constant (8 °C)	+ +	I
	High (12 °C)	-	II & IV

Quality scale: The best (+ +); Medium (+ -); Bad (-)

Strawberries exposed to low temperature always showed better quality, for all but the last day when strawberries stored at constant temperature had better quality than those at low temperature (Table 3).

Strawberries stored initially in a lower temperature had less decay in the first two days.
At the end of the storage period, the opposite happened: strawberries stored in a high temperature in the beginning had less decay.
The difference in quality in each instance was due to different temperature histories. For example: regime III and IV were both at low temperature at day six but before that, regime III had 4 days at 12°C and 2 days at 4°C, while regime IV was the opposite: 4 days at 4°C and 2 days at 12°C.
After 9 days, the difference in quality was not only due to different times and temperatures but also due to more temperature oscillations. For example: regime III and V both had in the total storage period 4 days at 12°C and 5 days at 4°C, but regime V had more temperature fluctuations than regime III which had resulted in a worse product quality.
Oscillations in the percentage of decay, during 6 days of storage, correspond to temperature fluctuations. At the end of the storage period, there were however no differences between two opposite temperatures regimes.

10. Conclusions

After analysing the results of the experiment, it is possible to conclude that strawberry quality react according to a temperature history.
With high temperatures at the beginning of storage followed by low temperatures, strawberries had less decay. With low temperatures at the beginning of storage, followed by high temperatures until the end of the storage period, the quality was worst.

V Cooling Experiment:

The propose of this fifth cooling experiment was to simulate the present situation in terms of time and temperature in actual strawberry logistics and some possible optimisations of it, as shown in Table 4 and Figs. 14 and 15.

Table 4
Temperature profiles that strawberries were exposed to during the fifth cooling regime.

Temp Profile	Initial T (°C) /t (h)	Cooling T (°C)/t (h)	Closing trays T(°C)/t (h)	Before transport T(°C)/t (h)	Transport T(°C)/t (h)	Shelf T(°C)
I	12 /12	4 / 6	12 / 0.7	12 / 3.3	6 / 24	18
II	8 /12	4 / 6	8 / 0.7	8 / 3.3	6 / 24	18
III	20	4 / 2	8 / 0.7	4 / 1.3 8 / 2	6 / 24	18
IV	20	4 / 2	12 / 0.7	4 / 1.3 12 / 2	6 / 24	18
Steady 4°C	4 / 22				6 / 24	18
Steady 10°C	10 / 22				6 / 24	18

After cooling, all the trays were closed and placed in a room at 8°C or 12°C for 40 minutes, accordingly with each temperature profile (table).
Transportation was simulated (compressed simulation, time about 15 minutes), in a 6°C room, using a standard method that reproduced 200Km in a truck with air suspension.

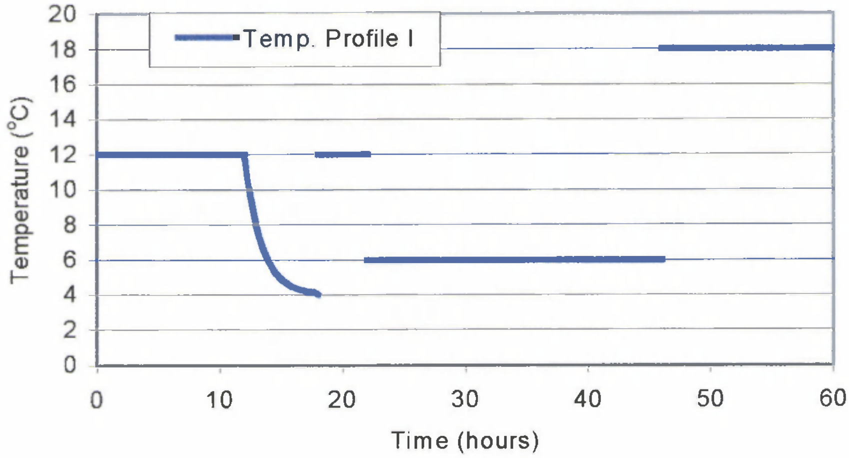


Fig. 14. Temperature profile illustrative the present situation.

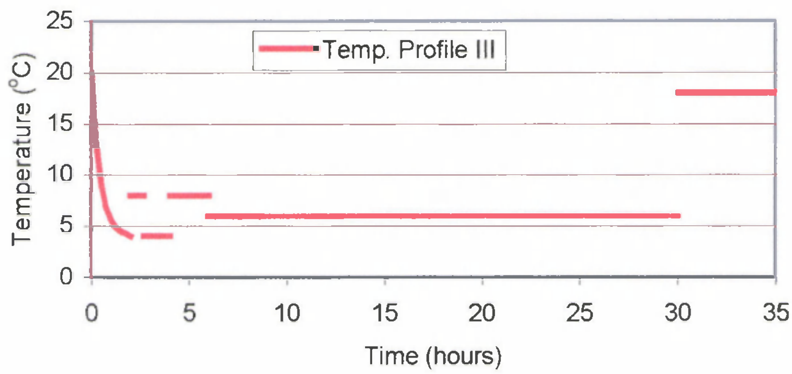


Fig. 15. Temperature profile describing a possible optimisation of the present situation.

11. Results

11.1. Decay

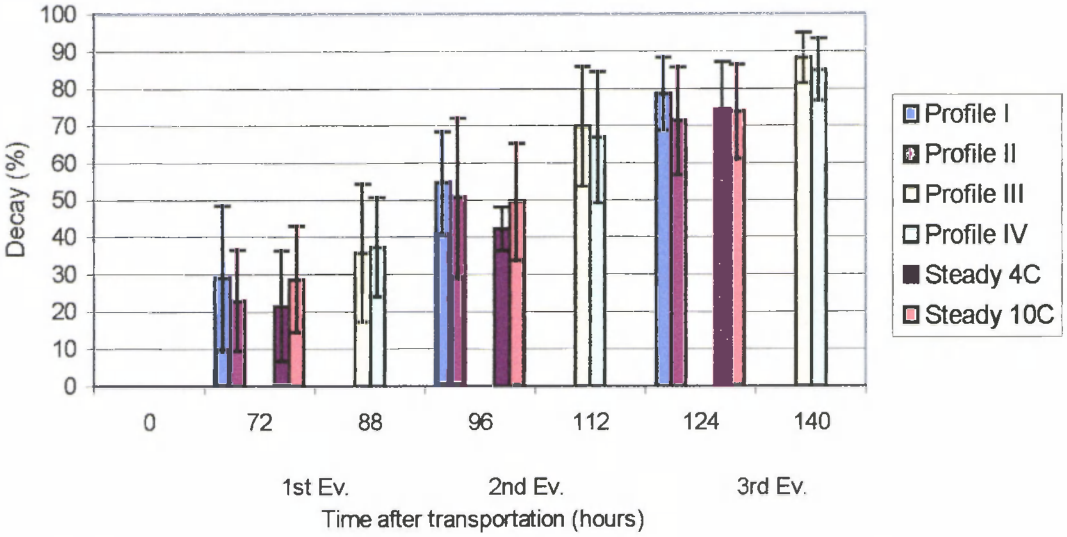


Fig. 16. Percentages of decay that strawberries showed after cooling down and stored accordingly with the fifth cooling experiment. First evaluation was after 72 and 88 hours, second evaluation after 96 and 112 hours and third evaluation after 124 and 140 hours.

Strawberries that had fast and immediate cooling (profile III and IV) finished all logistic process (spanning 24 hours till the end of transportation simulation) 16 hours before strawberries in other profiles, i.e., these strawberries were exposed to shelf conditions (18°C) 16 hours more than the strawberries stored correspondingly to other temperature profiles (profile I, II, steady 4C and steady 10C) (Fig. 16). All strawberries were evaluated in the same moment but with different hours of shelf conditions. Evaluation moments were selected at moment zero when transport simulation finished. So, the first evaluation was after 72 and 88h, the second evaluation after 96 and 112 hours and third evaluation after 124 and 140 hours.

There were no significant differences in terms of percentage of decay among the six temperature profiles in the three different evaluation moments.

Chart trends give the impression that:

♦ On the first evaluation moment (72 and 88 h after transportation):

There is some match between profile II and the profile with the lower steady temperature (4°C) due to identical average temperatures as well as profile I and the profile with steady temperature at 10°C.

The evaluations suggest that with immediate and fast cooling (profile III and IV), there is no positive contribution to strawberry quality. Profile III and IV 88 hours after (16 hours more than the other profiles – 72 hours) showed more decay (5-7%) than profile I and steady at 10°C and 15% more than profile II and steady at 4°C.

♦ On the second evaluation (96 and 112h after transportation):

Strawberries stored corresponding to the profile with the steady temperature at 4°C showed a less percentage of decay (43%).

In contrast, strawberries stored according to I profile showed the highest percentage of decay (55%) indicating that delayed cooling especially when exposed to high temperature (12°C) is bad for quality. However, these strawberries showed less decay when compared, 16 hours later (112 hours after transportation), with the ones that had immediate and fast cooling (profile III and IV). The percentage of decay of strawberries immediately cooled quickly (≈70%), 112 hours after transport is identical to the decay of the strawberries exposed to profile II, steady temperature at 4°C and at 10°C, 124 hours after transportation.

♦ On the third evaluation moment (124 and 140h after transportation):
Strawberries from profile I exhibited a higher percentage of decay (≈80%). The extreme percentage of decay was revealed in the strawberries from direct and fast cooling (profile III and IV) 140 hours after transportation (≈85-90%). For this, both temperature profiles have resulted in an inferior quality and this was revealed in the strawberries that were from profile III (≈90%), the situation that was also verified 112 hours after transportation.

11.2. Calyx Freshness

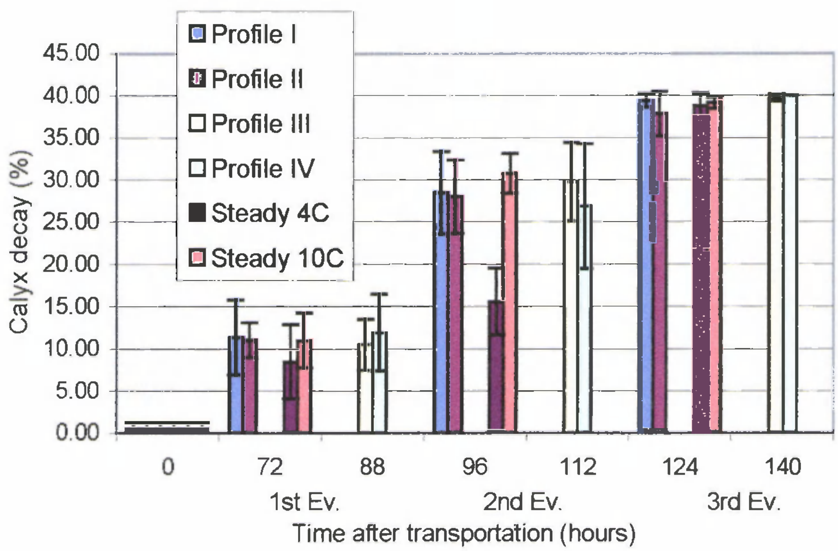


Fig. 17. Percentage of calyx decay in the strawberries from fifth cooling experiment.
There were no significant differences in calyx decay/freshness in each of the evaluation moments, besides in the second evaluation (96 hours after transportation) for the strawberries at 4°C steady temperature; these showed a fresher calyx than the strawberries from other temperature profiles (Fig. 17).

12. Conclusions

Fast and immediate cooling and a reduced delay between harvest and cooling do not contribute positively to strawberry quality when there are temperature fluctuations in the remaining storage period.

13. General Conclusions

Strawberry quality does not respond consistently to different regimes tested in the different experiments.

Nevertheless, it is possible to identify some probable factors that have a negative effect on fruit quality, such as:

- Temperature fluctuations
- Lids on the trays

There were other aspects that did not have a clear effect on strawberry quality, for instance:

- Cooling time
- Immediate or delay cooling
- Final temperature (4 or 8°C)

However, it is possible to mention the relative importance of these factors (Table 5).
Cooling strawberries at low temperature (4°C) seems favourable for strawberry quality, whether cooling is performed fast or slow. However, when cooling takes place very fast in combination with temperature fluctuations (TF), it is bad for fruit .

In case temperature fluctuations exist, it is preferable to have high temperatures in the beginning than at the end of the storage period.

Table 5
Effect on strawberry quality from some cooling parameters: Cooling temperature (4 or 8°C), cooling time (very fast, fast or slow) and moment of cooling (prompt or delayed cooling)

	Cooling temperature					
	4°C	8°C	4°C	8°C	4°C	8°C
Delay					+ – (TF)	–
Prompt	±	±	+ ± (TF)	–	+ – (TF)	±
	Very fast		**Fast**		**Slow**	

– negative, ± medium and + positive contribution on strawberry quality
TF – in case of temperature fluctuations

14. Further research

In this present study, the effect of some parameters – for instance, storage time, temperature fluctuations, closing trays, cooling time, immediate or delay cooling and final temperature – was analysed. Mostly, no significant correlations among these parameters and strawberry quality were found. Further study should be held focussing on certain aspects, always paying attention to what is happening in the supply chain in order to identify the decisive factors for product quality. Further research to gather more reliable data should focus on the following aspects: immediate cooling, reducing delay between harvest and cooling; Cooling speed - vacuum cooling or hydro vacuum cooling; cooling at the grower (pre-cooling systems quickly as possible); airflow rates – high-pressure fast cooling (HPFC); cooling type vs costs.

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