Effect of SmartFresh on the storage life of strawberry cv.Selva

Ian Wilkinson et al.
Agriculture Victoria

Project Number: BS00007

BS00007

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Final Report for HAL Project BS00007

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Final Report for Project BS00007

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Purpose of the report:
This project (BS00007) aimed to:

1. Quantify the benefits of SmartFresh in extending the storage life of strawberry cv. Selva.
2. Determine the optimum concentration and exposure time of SmartFresh.
3. Determine the effect of fumigation temperature on SmartFresh efficacy.

Funded by:
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Ian Wilkinson and Bruce Tomkins.

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MEDIA SUMMARY

SmartFresh [a.i. 3.3% 1-methylcyclopropene (1-MCP)] previously known as EthylBloc can block the action of ethylene in harvested fruit and vegetables. Ethylene is a natural fruit ripening hormone. Therefore, SmartFresh could be extremely useful as a post harvest treatment to extend the storage life of strawberries.

A series of experiments were conducted in 2001 using strawberry cv. Selva fruit picked in Autumn and late Spring / early summer, to evaluate the potential of SmartFresh to extend the storage life of strawberries. SmartFresh was used at the concentration range of 15 to 2000 parts per billion (ppb) for 2 to 4 hours and applied to pre-cooled fruit (2.5°C pulp temperature) and warm (15°C pulp temperature) fruit. The fumigation room temperatures were 2.5°C and 20°C respectively.

In general, SmartFresh did not have a significantly effect on the storage quality (firmness, colour, gloss) of strawberry cv. Selva, compared to fruit not treated with SmartFresh over a storage period of 2 to 9 days at 5°C. However, there were some exceptions to this. For example, the firmness of fruit treated with 15 ppb 1-MCP in the absence of exogenous ethylene was significantly firmer compared to fruit not treated with Smartfresh.

Previous reports have found that the level of rots in strawberries may increase if the fruit is exposed to high concentrations of SmartFresh greater than 50 ppb. In this study, the incidence of rots was generally acceptable for up to 4 days and there was no significant effect of SmartFresh at concentrations ranging from 100 ppb to 2000 ppb on the incidence of rots. Rots were more a problem associated with picking damage and injuries associated with squeezing the fruit into punnets at packing. Rapid cooling after harvest significantly reduced the incidence of rots.

Improved objective quality assessment methods for strawberries are needed. Consumers want bright red berries with high gloss and free from rots and blemishes. However, visual assessments can vary depending on who does the assessment. Researchers need objective methods to remove the guesswork. Rots can be assessed visually because any level of rot is unacceptable, but colour gloss and firmness need to be assessed using objective measurements. Methods to measure objective quality assessments need to be evaluated, to enable accurate measurement of changes in strawberry quality. Such measures can then be used by the strawberry industry to quantify strawberry quality.

SmartFresh did not significantly extend the storage life of strawberry cv. Selva. in the studies reported here. However, before it can be concluded that SmartFresh has no significant effect on the storage life of strawberries longer treatment times up to 24 hours should be tested. Furthermore, objective quality assessment methods must be developed to quantify strawberry fruit quality.

TECHNICAL SUMMARY

SmartFresh [a.i. 3.3% 1-methylcyclopropene (1-MCP)] previously known as EthylBloc can block the action of ethylene in harvested fruit and vegetables. Ethylene is a natural fruit ripening hormone. Therefore, SmartFresh could be extremely useful as a post harvest treatment to preserve the storage life of strawberries.

The aims of the project were:

1. Quantify the benefits of SmartFresh to extend the storage life of strawberry cv. Selva.
2. Determine the optimum concentration and exposure time of fruit to SmartFresh.
3. Determine the effect of fumigation temperature on SmartFresh efficacy.
4. Determine if high concentrations of SmartFresh adversely affect strawberry quality.
5. Determine if SmartFresh can block the effect of exogenous ethylene on fruit quality.

Strawberry cv. Selva picked in late autumn and late spring to early summer were used in a series of experiments to evaluate the effects of SmartFresh on the fruit's storage life. SmartFresh was used at the concentration range of 15 to 2000 parts per billion (ppb) for 2 to 4 hours and applied to pre-cooled (2.5°C pulp temperature) fruit and warm (15°C pulp temperature) fruit. The fumigation room temperatures were 2.5°C and 20°C respectively.

In general, irrespective of the concentration, exposure time and fumigation temperature, SmartFresh did not significantly affect the storage quality (firmness, colour, gloss) and did not affect the incidence of rots of strawberry cv. Selva compared to fruit not treated with SmartFresh over a storage period of 2 to 9 days at 5°C.

Exposure of strawberry cv. Selva to ethylene at 0.4 to 1 parts per million (ppm) did not significantly reduce the storage life. Given that SmartFresh's mode of action is to block the action of ethylene, the failure to detect adverse effects of applied ethylene on fruit quality could in part explain why there were no significant results in the current series of experiments.

Previous reports have found that SmartFresh at concentrations greater than 50 ppb may increase the incidence of rots in strawberry fruit. In our experiments, SmartFresh was used in a range of 100 ppb to 2000 ppb and there was no significant increase in the incidence of rots compared to fruit not treated with SmartFresh.

Consumers want bright red berries with high gloss which are free from rots and blemishes. However, visual assessments of the fruit quality can vary depending on who does the assessment. Researchers need objective methods to remove the guesswork. Rots can be assessed visually because any level of rots is unacceptable but colour, gloss and firmness need to be measured objectively. Methods to quantify fruit quality need to be developed and evaluated to enable more accurate measurement of changes in strawberry quality. The development of such tests would be a useful tool for the strawberry industry to quantify fruit quality.

SmartFresh did not significantly extend the storage life of strawberry cv. Selva. in the studies reported here. However, before it can be concluded that SmartFresh has no significant effect on the storage life of strawberries longer treatment times should be tested. Furthermore, to better quantify changes in strawberry quality, improved objective quality assessment methods must be developed.

INTRODUCTION

SmartFresh [3.3% a.i. 1-methylcyclopropene (1-MCP)] previously known as EthylBloc is an innovative product that can block the action of ethylene in harvested fruit and vegetables. Ethylene is a ripening hormone that promotes aging and senescence, so SmartFresh could be extremely useful as a pre-storage, pre-transport and / or pre-marketing treatment to preserve the shelf life of fruit and vegetables.

Overseas research has found that 1-MCP can delay softening and de-greening of many harvested fruits and vegetables and delays aging in flowers and pot plants.

Rohm and Haas P/L are the owners of SmartFresh. They have identified strawberries as a major potential market and approached IHD to conduct experiments to determine the effect of SmartFresh on their shelf life.

Strawberries keep for a few days at most normal marketing temperatures and can be stored for around 10 days at 0°C with weight loss, softening, loss of gloss and rots the factors limiting storage life.

Fumigation of strawberries with 5 to 15 ppb SmartFresh for 2 hours at 20°C extended the post harvest storage life by approximately 35% at 20°C and 150% at 5°C [Ku, et al. (1999)]. However, Ku et al. (1999) pointed out the reliability of using SmartFresh at such low concentrations in commercial conditions needs to be assessed. In addition, at higher concentrations there was an accelerated loss of strawberry quality. As this is the only report in which high concentrations of SmartFresh had an adverse effect on produce quality, this issue warrants further investigation. Strawberries need to be cooled quickly to 2°C or below after picking to maximise their shelf life. However, SmartFresh is sometimes physiologically more active if applied at room temperature (20°C). Therefore, the effect of a 2 hours delay in cooling of the fruit on fruit quality, offset by the potential benefits of SmartFresh, needs to be quantified.

The cultivar Selva will be used for the experiments because it is the main cultivar grown in Victoria up to 80% of production and a major cultivar in Queensland around 40% of production and it was used by Ku et al. (1999) in their experiments. The fruit will be picked from 2 years old plants because it is more perishable than fruit picked from very young plants.

The main objectives of this work is to see whether SmartFresh can extend the shelf life of strawberries and provide efficacy data to obtain registration of the product for use in Australia.

1. EXPERIMENTAL OBJECTIVES

1. Quantify the benefits of SmartFresh to extend the storage life of strawberry cv. Selva.
2. Determine the optimum concentration and exposure time of fruit to SmartFresh.
3. Determine the effect of fumigation temperature on SmartFresh efficacy.
4. Determine if high concentrations of SmartFresh adversely affect strawberry quality.
5. Determine if SmartFresh can block the effect of exogenous ethylene on fruit quality.

2. MATERIALS AND METHODS

Experiment 1. ***Effect of SmartFresh concentration applied at 20°C on the storage life of strawberry cv. Selva with no exogenous ethylene challenge.***

Handling, fumigation and storage

Strawberry fruit, cultivar Selva, were harvested commercially and pre-sized (large fruit, weighing approximately 14 grams) and graded to provide 20 uniform size and quality fruit per punnet. The fruit was transported to IHD and treated with 100 ppb, 250 ppb, 500 ppb or 1000 ppb (parts per billion) SmartFresh at 20°C for 2 hours. Control fruit received no SmartFresh. The fumigation technique to apply the SmartFresh used a 150 litre fumigation chamber which consisted of a stainless steel base with a perspex lid and the chamber was sealed by a water moat (Plate 1). A vial containing a measured amount of SmartFresh powder was taped to the inside of the perspex lid, below a septum injection hole. A measured volume of water (16 ml per gram of SmartFresh) was injected into the vial to release 1-MCP from the SmartFresh powder. A small electric pump was used to circulate the air and 1-MCP inside the chamber. After the SmartFresh fumigation treatment the fruit was transferred to 5°C (Plate 2). After 2, 5 and 7 days the fruit quality was assessed with respect to firmness, gloss, colour, rots and overall market quality.

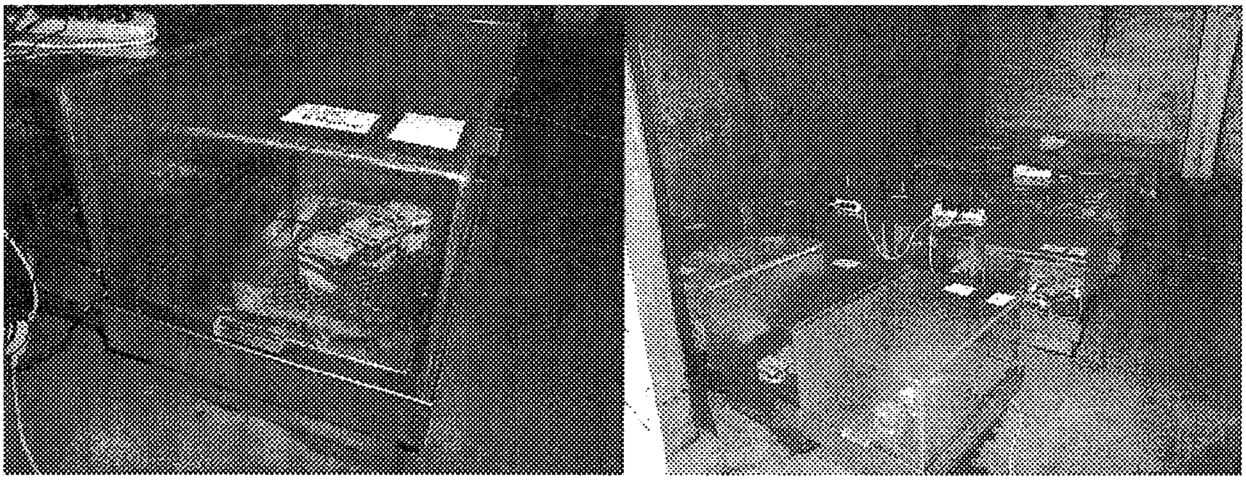


Plate 1. Fumigation chambers containing strawberry cv. Selva being fumigated with SmartFresh. A small electric pump was used to circulate the air inside the chamber.

Experimental Design:

5 SmartFresh concentrations x 3 removal times x 3 replicate blocks x 20 fruit per replicate

Concentrations: SmartFresh at 0 ppb, 100 ppb, 250 ppb, 500 ppb and 1000 ppb

Time x temperature: 2 hours at 20°C

Removal times: 2, 4 and 7 days storage

Statistical Analysis:

Analysis of variance (ANOVA) using Genstat version 5.41 software.

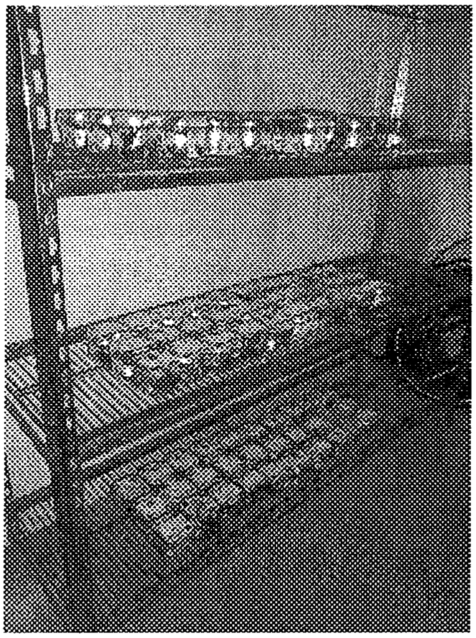


Plate 2. Strawberry cv. Selva in the 5°C storage room with the treatments grouped according to their fumigation treatment replicate blocks.

Experiment 1a. Effect of SmartFresh concentration applied at 20°C on the storage life of strawberry fruit cv. Selva subsequently challenged with exogenous ethylene.

Handling, fumigation and storage

The handling, fumigation and storage was the same as described for experiment 1 except that after the 2 hour fumigation the fruit was exposed to 0.4 ppm (parts per million) ethylene for 24 hours at 20°C before being placed at 5°C.

Experimental design:

The experimental design was the same as Experiment 1, except that the fruit was exposed to ethylene at 0.4 ppm at 20°C for 24 hours before being transferred to the 5°C shelf-life assessment room.

Statistical Analysis:

Analysis of variance (ANOVA) using Genstat version 5.41 software.

Experiment 2. Effect of SmartFresh concentration applied at 2.5°C on the storage life of strawberry fruit cv. Selva with no exogenous ethylene challenge.

Handling, fumigation and storage

Strawberry fruit, cultivar Selva, were harvested commercially, sized (14 g fruit), graded, 18 fruit were packed per punnet, and the fruit was pre-cooled to 2.5°C. The fruit was transported to IHD and treated with 500 ppb, 1000 ppb or 2000 ppb SmartFresh at 2.5°C for 4 hours. Control fruit received no SmartFresh. The SmartFresh fumigation technique used the fumigation chambers described in experiment 1. A standard concentrate (20,000,000 ppb) was prepared by weighing 1.36 grams of SmartFresh powder into a 1 litre flask which was sealed with an air tight septum. A measured volume of water (16 ml per gram of SmartFresh) was injected into the flask to release 1-MCP from the SmartFresh powder. A measured volume of 1-MCP gas was taken from the concentrate to deliver the required treatment concentration inside the fumigation chamber. The volume of 1-MCP gas taken from the concentrate was replaced with saturated ammonium sulphate to avoid creating a pressure gradient difference between the inside and outside of the flask which can lead to 1-MCP escaping during sampling. Each fumigation chamber contained a small air pump to create some air circulation. After the SmartFresh fumigation the fruit was transferred to 5°C and the fruit quality with respect to firmness, gloss, colour, rots and market quality was assessed after 2, 5 and 7 days storage.

Experimental Design:

5 SmartFresh concentrations x 3 removal times x 3 replicate blocks x 18 fruit per replicate.

Concentrations:	SmartFresh at 0 ppb, 250 ppb, 500 ppb, 1000 ppb and 2000 ppb
Time x temperature:	4 hours at 2.5°C
Removal times:	2, 4 and 7 days storage

Statistical Analysis:

Analysis of variance (ANOVA) using Genstat version 5.41 software.

Experiment 2a. Effect of SmartFresh concentration when applied at 2.5°C on the storage life of strawberry cv. Selva, subsequently challenged with exogenous ethylene.

Handling, fumigation and storage

The handling, fumigation and storage was the same as described for experiment 2 except that after the 4 hour fumigation the fruit was exposed to 0.4 ppm ethylene for 24 hours at 2.5°C before being placed at 5°C.

Experimental Design:

The experimental design was the same as Experiment 2, except that the fruit was exposed to ethylene at 0.4 ppm at 2.5°C for 24 hours before being transferred to the 5°C shelf-life assessment room.

Statistical Analysis:

Analysis of variance (ANOVA) using Genstat version 5.41 software.

Experiment 3. Effect of SmartFresh concentration and exposure time when applied at 2.5°C on the storage life of strawberry cv. Selva subsequently challenged or not challenged with exogenous ethylene.

Handling, fumigation and storage

Strawberry fruit, cultivar Selva, were harvested commercially, sized (14 g fruit), graded, 18 fruit was packed per punnet and the fruit was pre-cooled 2.5°C. The fruit was transported to IHD and treated with 15 ppb, 50 ppb, 200 ppb or 500 ppb SmartFresh at 2.5°C for 1, 2 or 4 hours. Control fruit received no SmartFresh. The SmartFresh fumigation technique was the same as reported for experiment 2, except that two standard concentrates were used 2,000,000 and 20,000,000 ppb. Each fumigation chamber contained a small air pump to create some air circulation. The fumigation was done sequentially starting with the longest exposure time so that the ethylene challenge of 1 ppm for 24 hours at 5°C could be undertaken for all exposure times at the same time. Those treatments not being challenged with ethylene were held in 5°C air. After the ethylene challenge all of the treatments were held in air at 5°C and the fruit quality with respect to firmness, colour and rots were assessed after 2, 5 and 7 days.

Experimental Design:

4 SmartFresh concentrations x 3 exposure times x 2 ethylene x 3 removal times x 4 replicate blocks x 18 fruit replicate.

Concentrations:	SmartFresh at 0 ppb, 15 ppb, 50 ppb and 500 ppb
Time x temperature:	1, 2 and 4 hours at 2.5°C
Ethylene:	+/- 1 ppm at 5°C for 24 hours
Removal times:	2, 4 and 7 days storage

Statistical Analysis:

Analysis of variance (ANOVA) using Genstat version 5.41 software.

Experiment 4. Effect of SmartFresh applied at 2.5°C or 15°C on the storage life of strawberry cv.Selva, subsequently challenged or not challenged with exogenous ethylene.

Handling, fumigation and storage

Strawberry fruit, cultivar Selva, were harvested commercially and sized (14 g fruit), graded and 18 fruit was packed per punnet. Half of the strawberry punnets were pre-cooled to 2.5°C at the growers' facilities with the remainder not cooled. The fruit was transported to IHD and treated with SmartFresh at 2.5°C (pre-cooled) for 4 hours or at 20°C (not cooled) for 2 hours. The SmartFresh fumigation technique was the same as described for experiment 2. After the SmartFresh fumigation was complete the fumigation chambers used for the 20°C treatment were transferred to the 2.5°C room at which time the room temperature was raised to 5°C. Each fumigation chamber contained a small air pump to create some air circulation. Half of the treatment chambers were subsequently challenged with ethylene at 1ppm for 21 hours at 5°C, after which ethylene challenged fruit and the fruit not challenged with ethylene were transferred to another 5°C room. The punnets of fruit were placed on shelves in their treatment blocks to simulate local market handling. Fruit quality with respect to firmness, rots and colour was assessed after 3, 6 and 9 days.

Experimental Design:

2 SmartFresh concentrations x 1 exposure time x 2 fumigation temperatures x 2 ethylene x 3 removal times x 6 replicate blocks x 18 fruit per replicate.

Concentrations:	SmartFresh at 0 ppb and 15 ppb
Time x temperature:	4 hours at 2.5°C or 2 hours at 20°C
Ethylene:	+ / - 1 ppm at 5°C for 21 hours
Removal times:	3, 6 and 9 days storage

Statistical Analysis:

Analysis of variance (ANOVA) using Genstat version 5.41 software.

Measurements and assessments

Temperature

Ambient air temperature was monitored on a 24 hour basis during the storage period.
The rooms were within ±0.5°C of the set point.

Quality Assessments

Firmness: Fruit firmness was measured using an Ametek® Accuforce 111 force gauge unit (Plate 3). The Ametek® unit was fitted with a 3 mm diameter flattened end probe. The force gauge unit was used for measuring the fruit firmness for all of the experiments. Firmness is expressed as kgf.

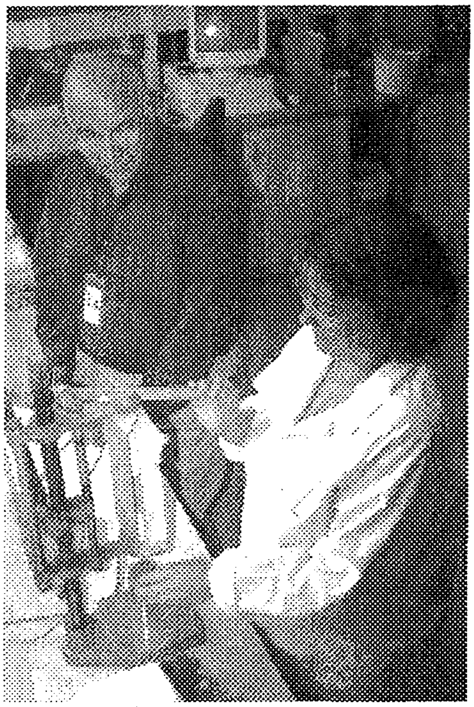


Plate 3. Fouad Goubran and Christine Frisina measuring strawberry firmness using the Ametek® force gauge unit.

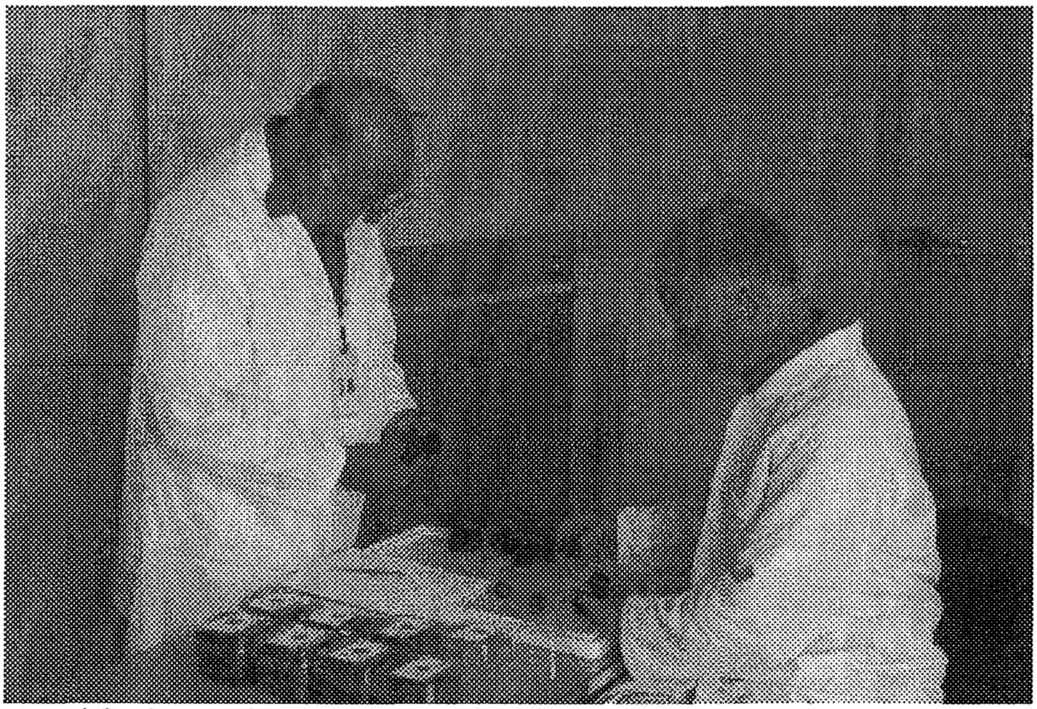


Plate 4. Fouad Goubran and Ian Wilkinson doing the visual quality assessment for fruit colour of strawberry cv. Selva after treatment and storage.

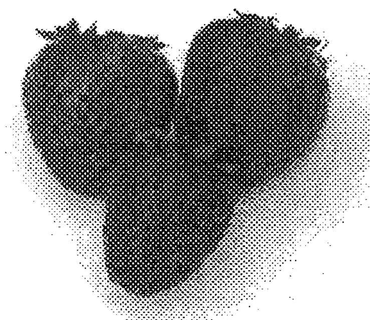
Fruit colour: Fruit was graded into pale (1), red (2) and dark red (3) (Plate 4) and the average colour rating was calculated using the following formula.

Average colour rating = [(n x P1) + (n x R2) + (n x D3)] / Total number of fruit

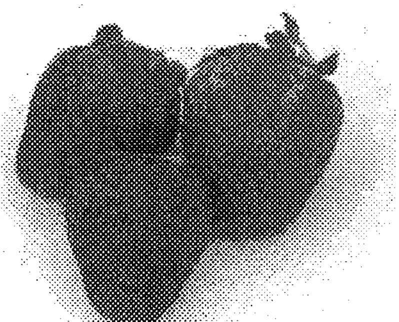
n = number of fruit
P1 = number of pale fruit x rating 1, R2 = number of red fruit x rating 2 and D3 = number of dark red fruit x rating 3.
The higher the rated % the darker the fruit colour. Conversely, lower values represent a paler fruit colour.

Rated red colour was used in experiments 1, 1a, 2, and 2a.

Acceptable colour rating: Two colour standards were used, unacceptable DARK and acceptable LIGHT (Plate 5). The incidence of fruit with acceptable colour was recorded and expressed as a percentage for experiment 3 and 4.



Unacceptable DARK



Acceptable LIGHT

Plate 5. Two colour standards unacceptable DARK and acceptable LIGHT used for experiments 3 and 4.

Fruit gloss: Fruit was graded into low (1), medium (2) and high (3) gloss fruit and the average gloss rating was calculated using the following formula.

Average gloss rating = [(n x L1) + (n x M2) + (n x H3)] / Total number of fruit

n = number of fruit
L1 = Number of low gloss fruit x rating 1, M2 = number of medium gloss fruit x rating 2 and H3 = number of high gloss fruit x rating 3.

Rated gloss was used in experiments 1, 1a, 2, and 2a.
The higher the rating % the more glossy the fruit. Conversely, lower values represent lower gloss fruit.

Incidence of rots: Incidence of fruit with rots were recorded and expressed as a percentage of fruit affected in all experiments.

Market quality: Market quality was rated using a subjective quality rating scale where 1 equals lowest quality and 10 equals the highest quality (field fresh). The market quality rating scale was used for experiments 1, 1a, 2, and 2a.

Photographs
Photographs were taken to record significant treatment effects.

3. RESULTS

Experiment 1. Effect of SmartFresh concentration applied at 20°C on the storage life of strawberry cv. Selva with no exogenous ethylene challenge.

Firmness

The firmness (kgf) of strawberry cv. Selva after 2 days at 5°C treated with SmartFresh concentrations 250 ppb and 500 ppb for 2 hours at 20°C were significantly firmer than the not treated (control) fruit (Table 1). Fruit treated with SmartFresh at 100 ppb and 1000 ppb were not significantly firmer than fruit treated with the 0 ppb fruit (control fruit). After 4 and 7 days at 5°C there was no significant effect of SmartFresh concentration on fruit firmness compared to fruit not treated with SmartFresh.

The firmness of fruit not treated with SmartFresh and stored at 5°C were significantly softer after 2 days compared to the fruit after 4 and 7 days. The firmness of control fruit after 4 and 7 days were not significantly different to the firmness of fruit treated with SmartFresh concentrations of 250 ppb and 500 ppb after 2 days at 5°C.

Incidence of rots

The incidence of rots of fruit treated with SmartFresh at 100 ppb, 250 ppb, 500 ppb and 1000 ppb was not significantly different compared to fruit not treated with SmartFresh after 4 days at 5°C (Table 2, Plate 6). After 7 days at 5°C fruit treated with SmartFresh at 500 ppb had significantly more rots compared to control fruit being 36.7% and 20% respectively. However, there was no significant effect of the 100 ppb, 250 ppb and 1000 ppb SmartFresh concentration on the incidence of rots compared to fruit not treated with SmartFresh.

Fruit colour

The average colour rating of fruit treated with SmartFresh at 100 ppb, 250 ppb, 500 ppb and 1000 ppb was not significantly different compared to fruit not treated with SmartFresh after 2, 4 and 7 days at 5°C (Table 3).

Fruit gloss

The average gloss rating of fruit treated with SmartFresh at 100 ppb, 250 ppb, 500 ppb and 1000 ppb was not significantly different compared to fruit not treated with SmartFresh after 2 and 7 days at 5°C (Table 4). However, after 4 days at 5°C fruit treated with SmartFresh at 250 ppb and 500 ppb were significantly glossier compared to fruit not treated with SmartFresh, although the rated gloss varied significantly between the storage times. For example, control fruit after 4 days at 5°C had a rated gloss of 71% compared to 82.8% after 7 days.

Market quality

The market quality of fruit treated with SmartFresh at 100 ppb, 250 ppb, 500 ppb and 1000 ppb was not significantly different compared to fruit not treated with SmartFresh after 2 and 4 days at 5°C (Table 5). However, the market quality of fruit treated with 250 ppb SmartFresh was significantly better compared to fruit not treated with SmartFresh. Conversely, the market quality of fruit treated with 500 ppb SmartFresh was significantly quality compared to fruit not treated with SmartFresh.

Experiment 1a. Effect of SmartFresh concentration applied at 20°C on the storage life of strawberry fruit cv. Selva, subsequently challenged with exogenous ethylene.

Firmness

The firmness of fruit treated with SmartFresh at 100 ppb, 250 ppb, 500 ppb and 1000 ppb was not significantly different compared to fruit not treated with SmartFresh after 2, 4 and 7 days at 5°C (Table 6).

Incidence of rots

The incidence of rots of fruit treated with SmartFresh at 100 ppb, 250 ppb, 500 ppb and 1000 ppb was not significantly different from fruit not treated with SmartFresh after 1, 3 and 6 days at 5°C (Table 7).

Fruit colour

The average colour rating for fruit treated with SmartFresh at 100 ppb, 250 ppb, 500 ppb and 1000 ppb was not significantly different from fruit not treated with SmartFresh after 1, 3 and 6 days at 5°C (Table 8).

Fruit gloss

The average gloss rating for fruit treated with SmartFresh at 100 ppb, 250 ppb, 500 ppb and 1000 ppb was not significantly different from fruit not treated with SmartFresh after 1, 3 and 6 days at 5°C (Table 9).

Market quality

The market quality of fruit treated with SmartFresh at 100 ppb, 250 ppb, 500 ppb and 1000 ppb was not significantly different compared to fruit not treated with SmartFresh after 1 and 3 days at 5°C (Table 10). However, after 6 days at 5°C the market quality of fruit treated with SmartFresh at 500 ppb and 1000 ppb was significantly poorer than fruit not treated with SmartFresh.

Experiment 2. Effect of SmartFresh concentration applied at 2.5°C on the storage life of strawberry fruit cv. Selva with no exogenous ethylene challenge.

Firmness

The firmness of fruit treated with SmartFresh at 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C was not significantly different from fruit not treated with SmartFresh after 2 and 7 days at 5°C (Table 11). However, after 4 days at 5°C, fruit treated with SmartFresh at 500 ppb, 1000 ppb and 2000 ppb were significantly firmer than fruit not treated with SmartFresh.

Incidence of rots

The incidence of rots in fruit treated with SmartFresh at 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C was not significantly different from fruit not treated with SmartFresh after 2, 4 and 7 days at 5°C (Table 12).

Rated colour

In general, the average colour rating of fruit treated with SmartFresh at 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C was not significantly different from fruit not treated with SmartFresh after 2, 4 and 7 days at 5°C (Table 13). However, after 2 days at 5°C fruit treated with 500 ppb SmartFresh had a significantly darker colour than the fruit not treated with SmartFresh and the fruit treated with 250 ppb, 1000 ppb and 2000 ppb.

Rated gloss

The average gloss rating of fruit treated with SmartFresh at 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C was not significantly different from fruit not treated with SmartFresh after 2, 4 and 7 days at 5°C (Table 14).

Market quality

In general, the market quality of fruit treated with SmartFresh at 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C was not significantly different from fruit not treated with SmartFresh after 2, 4 and 7 days at 5°C (Table 15). However, after 2 days fruit treated with 250 ppb SmartFresh had significantly lower market quality compared to the control fruit. In addition, after 7 days at 5°C fruit treated with SmartFresh at 250 ppb and 1000 ppb had significantly lower market quality compared to fruit not treated with SmartFresh.

Experiment 2a. Effect of SmartFresh concentration when applied at 2.5°C on the storage life of strawberry cv. Selva, subsequently challenged with exogenous ethylene.

Firmness

The firmness of fruit treated with SmartFresh at 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C followed by exposure to 0.4 ppm ethylene for 24 hours were not significantly different compared to fruit not treated with SmartFresh after 1 and 3 days at 5°C (Table 16). However, after 6 days at 5°C fruit treated with SmartFresh at 500 ppb and 2000 ppb were significantly softer than fruit not treated with SmartFresh.

Incidence of rots

The incidence of rots in fruit treated with SmartFresh at 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C followed by exposure to 0.4 ppm ethylene for 24 hours were not significantly different compared to fruit not treated with SmartFresh after 1, 3 and 6 days at 5°C (Table 17).

Fruit colour

The average colour rating of fruit treated with SmartFresh at 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C, followed by exposure to 0.4 ppm ethylene for 24 hours were not significantly different compared to fruit not treated with SmartFresh after 1, 3 and 6 days at 5°C (Table 18).

Fruit gloss

The average gloss rating of fruit treated with SmartFresh at 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C, followed by exposure to 0.4 ppm ethylene for 24 hours was not significantly different compared to fruit not treated with SmartFresh after 1, 3 and 6 days at 5°C (Table 19).

Market quality

The market quality of fruit treated with SmartFresh at 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C, followed by exposure to 0.4 ppm ethylene for 24 hours was not significantly different compared to fruit not treated with SmartFresh after 1, 3 and 6 days at 5°C (Table 20).

Experiment 3. Effect of SmartFresh concentration and exposure time when applied at 2.5°C on the storage life of strawberry cv. Selva, subsequently challenged or not challenged with exogenous ethylene.

Firmness

After 7 days at 5°C, the firmness of fruit treated with SmartFresh at 15 ppb, 50 ppb, 100 ppb and 500 ppb was not significantly different from fruit not treated with SmartFresh (Table 21).

There was no significant effect of fumigation exposure time of 1 hour, 2hours and 4 hours at 2.5°C on fruit firmness (Table 22).

There was no significant effect on fruit firmness of exposing the fruit to 1ppm ethylene for 24 hours at 2.5°C before storage after 7 days at 5°C (Table 23).

The fruit softened significantly in storage from day 2 to day 4 and day 4 to day 7 (Table 24).

Fruit colour

After 7 days at 5°C, the percentage of fruit treated with SmartFresh at 15ppb, 50 ppb, 100 ppb and 500 ppb with any acceptable colour rating was not significantly different from fruit not treated with SmartFresh (Table 25).

There was no significant effect of the fumigation exposure time after 1 hour, 2hour and 4 hours at 2.5°C on the acceptable colour rating of fruit (Table 26).

After 7 days at 5°C, there was no significant effect on the acceptable colour rating of fruit by exposing them to 1 ppm ethylene for 24 hours at 2.5°C before storage (Table 27).

The fruit acceptable colour rating significantly decreased during storage between days 2 to 4 and days 4 to 7 (Table 28).

Incidence of rots

The incidence of rots in fruit treated with SmartFresh at 15 ppb, 100 ppb, 50 ppb and 500 was not significantly different to fruit not treated with SmartFresh after 7 days at 5°C (Table 29).

There was no significant effect of the fumigation exposure time after 1 hour, 2 hours and 4 hours at 2.5°C on percentage incidence of rots in fruit irrespective of the ethylene, concentration and exposure time (Table 30).

There was no significant effect on the incidence of rots of exposing the fruit to 1 ppm ethylene for 24 hours at 2.5°C before storage after 7 days at 5°C (Table 31).

The mean incidence of rots for all treatments significantly increased in storage between days 2 to 4 and days 4 to 7 (Table 32).

Experiment 4. Effect of SmartFresh concentration applied at 2.5°C or 20°C on the storage life of strawberry cv. Selva subsequently challenged or not challenged with exogenous ethylene.

Firmness

The firmness of fruit treated with 15 ppb SmartFresh and exposed to ethylene at 1 ppm for 21 hours was not significantly different compared to fruit not treated with ethylene (Table 33). However, if the fruit was not exposed to ethylene, the fruit treated with SmartFresh was significantly firmer compared to the fruit not treated with SmartFresh.

The firmness of fruit treated with 15 ppb SmartFresh at 2.5°C for 4 hours was significantly greater than fruit not treated with SmartFresh after 9 days at 5°C (Table 34). There was no significant difference in the firmness of fruit treated with 15 ppb SmartFresh at 2.5°C after 3 and 6 days at 5°C from fruit not treated with SmartFresh. There was no significant difference in the firmness of fruit treated with 15 ppb SmartFresh at 20°C for 2 hours compared to fruit not treated with SmartFresh after 3, 6 and 9 days at 5°C.

There were no significant interactions of the SmartFresh concentration, fumigation temperature, storage time with the ethylene effect on fruit firmness.

Fruit colour

After 9 days at 5°C, the incidence of acceptable coloured fruit treated with 15 ppb SmartFresh at 2.5°C for 4 hours was significantly higher compared to fruit not treated with SmartFresh (Table 35). There was no significant difference in the incidence of acceptable coloured fruit treated with 15 ppb SmartFresh at 2.5°C after 3 and 6 days at 5°C. There was no significant difference in the incidence of acceptable coloured fruit treated with 15 ppb SmartFresh at 20°C for 2 hours compared to fruit not treated with SmartFresh after 3, 6 and 9 days at 5°C.

The incidence of acceptable coloured fruit significantly decreased in storage between days 3 to 6 and days 6 to 9.

There were no significant interactions of the SmartFresh concentration, fumigation temperature, storage time with the ethylene effect on fruit colour.

Incidence of rots

After 9 days at 5°C, the incidence of rots in fruit treated with 15 ppb SmartFresh at 2.5°C was significantly lower than fruit treated with SmartFresh at 20°C (Table 36). There was no significant difference in incidence of rots in fruit treated with 15 ppb SmartFresh at 2.5°C compared to fruit not treated with SmartFresh after 9 days at 5°C. Similarly, there was no significant difference in incidence of rots in fruit treated with 15 ppb SmartFresh at 20°C compared to fruit not treated with SmartFresh after 9 days at 5°C.

The fruit stored at 2.5°C had a significantly lower incidence of rots compared to fruit stored at 20°C, whether it was fumigated or not. The incidence of rots increased significantly between days 6 to 9.

There were no significant interactions of the SmartFresh concentration, fumigation temperature or storage time with the ethylene effect on the incidence of rots.

4. DISCUSSION AND CONCLUSIONS

Strawberries are classified as non-climacteric fruit. That is there is no substantial increase in ethylene production associated with fruit ripening (softening of the flesh and darkening of the red skin colour). However, while the level of endogenous ethylene produced during ripening by strawberries is small compared to climacteric fruit such as apples, it has been reported that exposure of strawberry fruit to ethylene greater than 0.005 ppm can significantly reduce the fruit's storage life (Wills, et al., 1999). Ethylene levels ranging from 0.03 to 1.17 ppm have been measured inside strawberry punnets (Wills and Kim, 1995 and Wills, et al., 1999). However, there was no adverse effect of ethylene (0.4 and 1 ppm) on the storage quality of strawberry cv. Selva, in the study reported here.

Given that SmartFresh blocks the action of ethylene, the failure of fumigation with SmartFresh to obtain significant effects on fruit quality may indicate that cv. Selva is relatively insensitive to ethylene.

In experiments 1, 1a, 2 and 2a high concentrations of SmartFresh ranging from 100 ppb to 2000 ppb were used and in subsequent experiments lower concentrations 15 ppb to 50 ppb were tested. SmartFresh at concentrations greater than 50 ppb have been associated with increased levels of rots in strawberry fruit (Ku et al. 1999, Jiang et al. 2001). Comparatively low levels of phenolics in the fruit treated with 1000 ppb could account for decreased disease resistance (Jiang et al. 2001). However, SmartFresh at concentrations in the range 50 ppb to 2000 ppb used in the current series of experiments did not have a consistent effect in significantly increasing the incidence of rots.

In the current series of experiments, the major cause of rots could be linked to the incidence of picking damage, punctures and finger compression marks independent of any SmartFresh effects. The style of plastic punnets used here appeared to contribute significantly to the reduced storage life of strawberries. Squeezing the fruit to fit into the base of the punnet damaged the fruit and provided sites for rot development (Plate 7).

Good quality strawberry fruit are firm, glossy, bright red and free of rots. The consumer makes a visual assessment of the fruit and determines if the quality is acceptable. The difficulty from a research point of view is that a visual assessment is subjective and can vary depending on who assesses the fruit. Better objective tests are needed to measure changes in strawberry quality. Strawberry firmness can be measured objectively by using a compression test or an Ametek® pressure unit. The compression test uses a 200 gram weight placed onto the berry to measure the compression of the fruit and thus determine changes in fruit firmness. The problem with this method is that fruit size and shape will significantly effect how much compression occurs. Therefore, to detect significant changes in fruit firmness due to SmartFresh, differences would need to be very large such as 0.1 to 0.3 kgf. The Ametek® pressure unit uses a 3 mm flat head probe and ignores the fruit shape and size effects. It records the peak compression force when penetrating the strawberry. However, it is possible that the 3 mm head is too small and may give lower values. A slightly larger head will create more compression which may provide a better correlation with fruit firmness. Whether Ametek® pressure unit method is better than the compression test in measuring fruit firmness is debatable but it may have contributed to the failure to detect significant changes in firmness of SmartFresh treated fruit compared to fruit not treated with SmartFresh.

Fruit colour was assessed visually in the current experiments and the results are subjective. A Minolta chromameter can be used to measure fruit colour expressed as a hue angle. Therefore, before commencing any further strawberry trials, the effectiveness of this method to be able to detect changes in the fruits red colour intensity should be investigated.

Gloss is a critical visual quality factor. A method to objectively measure the gloss of strawberry fruit needs to be established. This may involve the chromameter, which can measure the level of darkness and lightness of objects and generate an L-value. This would require some research to establish the effectiveness of the L-value to measure glossiness.

Rots can be visually assessed because the assessment is simply yes or no for rots because any rot, no matter what the severity, is unacceptable.

In experiments 3 and 4, SmartFresh at 15 ppb with a fumigation temperature at 2.5°C and 20°C did not improve fruit quality after 6 days at 5°C. Ku et al. (1999) also worked with strawberry cv. Selva and found that fruit treated with SmartFresh at 15 ppb doubled the storage life compared to fruit not treated with SmartFresh. However, the storage life of untreated fruit was only 2.3 days which is very short and the 5.1 days storage life of the SmartFresh treated fruit is what you could normally expect from untreated fruit stored properly. Jiang et al. (2002) found that the quality of cv. Everest was significantly improved with 100 ppb but not 10 ppb after 3 days at 20°C compared to fruit not treated with SmartFresh. Everest is a softer cultivar than Selva. Therefore, the commercial value of SmartFresh may be to increase the storage life of softer strawberry cultivars when held at room temperature.

In these experiments the exposure time of the fruit to SmartFresh was short (2 to 4 hours) depending on the fumigation temperature. This was intentional to simulate minimising the holding time of the fruit at the growers' property before the fruit could be shipped to the market place. However, many growers pre-cool the fruit overnight. Therefore, if further research was to be conducted on strawberries then it would be wise, to evaluate longer exposure times when using low SmartFresh concentrations such as 15 ppb, to maximise the potential benefits of SmartFresh on storage life.

5. RECOMMENDATIONS

- SmartFresh does not appear to extend the storage life of Selva strawberries if good post harvest temperature management is maintained.
- Before it can be concluded that SmartFresh has no significant effect on the storage life of strawberries longer treatment times up to 24 hours should be tested.
- The storage life of the fruit may be extended by not squeezing fruit into plastic punnets which potentially damages the fruit and provides sites for rots to develop. Alternative packaging should be investigated.
- Objective quality assessment methods need to be developed that can be used to better quantify fruit quality.

6. REFERENCES

Wills, R. B. H. and G.H. Kim (1995). Effect of ethylene on postharvest life of strawberries. Postharvest Biology and Technology, 6: 249-255.

Wills, R. B. H., Shohet, D. and G.H. Kim (1999). Importance of low ethylene levels to delay senescence of non-climacteric fruit and vegetables. Australian Journal of Experimental Agriculture, 39 : 221-224.

Ku, V. V.V., Wills, R. B. H. and S. Ben-Yehoshua (1999). 1-Methylcyclopropene can differentially affect the post harvest life of strawberries exposed to ethylene. HortScience, 34 (1): 119-120.

Jiang, Y., Joyce, D.C. and L.A. Terry (2001). 1-Methylcyclopropene treatment affects strawberry fruit decay. Postharvest Biology and Technology, 23:227-232.

7. TABLES

Table 1. Experiment 1. Effect of SmartFresh at 0 ppb, 100 ppb, 250 ppb, 500 ppb and 1000 ppb for 2 hours at 20°C on the firmness of strawberry cv. Selva, after 7 days at 5°C.

SmartFresh concentration ppb =parts per billion	Firmness (kgf)		
	Time (days at 5°C)		
	2	4	7
0 ppb	0.38	0.46	0.45
100 ppb	0.42	0.49	0.47
250 ppb	0.45	0.45	0.48
500 ppb	0.47	0.47	0.44
1000 ppb	0.43	0.47	0.48
LSD (*P=0.05*)[1]	0.06		

[1.] LSD = Least significant differences at the 5% significance level.

Table 2. Experiment 1. Effect of SmartFresh at 0 ppb, 100 ppb, 250 ppb, 500 ppb and 1000 ppb for 2 hours at 20°C on the percentage incidence of rots in strawberry cv. Selva, after 7 days at 5°C.

SmartFresh concentration ppb =parts per billion	Rots incidence (%)	
	Time (days at 5°C)	
	4	7
0 ppb	8.3	20.0
100 ppb	10.0	28.3
250 ppb	10.0	23.3
500 ppb	8.3	36.7
1000 ppb	3.3	30.0
LSD (*P=0.05*) comparing across rows[1]	15.4	
LSD (*P=0.05*) other	14.7	

[1.] LSD = Least significant differences at the 5% significance level.

Table 3. Experiment 1. Effect of SmartFresh at 0 ppb, 100 ppb, 250 ppb, 500 ppb and 1000 ppb for 2 hours at 20°C on the rated colour of strawberry cv. Selva, after 7 days at 5°C.

SmartFresh concentration ppb =parts per billion	Rated colour[1]		
	Time (days at 5°C)		
	2	4	7
0 ppb	2.1	2.4	2.1
100 ppb	2.0	2.3	2.0
250 ppb	1.9	2.4	1.9
500 ppb	1.9	2.4	2.0
1000 ppb	2.0	2.4	2.0
LSD (*P=0.05*) comparing across rows[2]	0.4		
LSD (*P=0.05*) other	0.4		

[1.] Rated colour %: Higher values represent darker colour fruit.
[2.] LSD = Least significant differences at the 5% significance level.

Table 4. Experiment 1. Effect of SmartFresh at 0 ppb, 100 ppb, 250 ppb, 500 ppb and 1000 ppb for 2 hours at 20°C on the rated gloss of strawberry cv. Selva, after 7 days at 5°C.

SmartFresh concentration ppb =parts per billion	Rated Gloss[1] Time (days at 5°C)		
	2	4	7
0 ppb	2.3	2.1	2.5
100 ppb	2.3	2.1	2.3
250 ppb	2.3	2.3	2.3
500 ppb	2.4	2.3	2.3
1000 ppb	2.2	2.2	2.4
LSD (*P=0.05*) comparing across rows[2]		0.2	
LSD (*P=0.05*) other		0.1	

1. Rated gloss %: Higher values represent glossier fruit.
2. LSD = Least significant differences at the 5% significance level.

Table 5. Experiment 1. Effect of SmartFresh at 0 ppb, 100 ppb, 250 ppb, 500 ppb and 1000 ppb for 2 hours at 20°C on the market quality of strawberry cv. Selva, after 7 days at 5°C.

SmartFresh concentration ppb =parts per billion	Market quality[1] Time (days at 5°C)		
	2	4	7
0 ppb	7.0	7.3	7.0
100 ppb	7.7	6.7	6.3
250 ppb	7.3	7.3	7.3
500 ppb	7.0	7.7	5.3
1000 ppb	6.3	6.0	6.7
LSD (*P=0.05*) comparing across rows[2]		1.7	
LSD (*P=0.05*) other		1.4	

1. Market quality: 1 equals the lowest quality and 10 highest quality field fresh.
2. LSD = Least significant differences at the 5% significance level.

Table 6. Experiment 1a. Effect of SmartFresh at 0 ppb, 100 ppb, 250 ppb, 500 ppb and 1000 ppb for 2 hours at 20°C on the firmness of strawberry cv. Selva, followed by exposure to ethylene at 0.4 ppm for 24 hours plus 6 days at 5°C.

SmartFresh concentration ppb =parts per billion	Firmness (kgf) Time (days at 5°C)		
	1	3	6
0 ppb	0.41	0.47	0.49
100 ppb	0.44	0.49	0.46
250 ppb	0.43	0.49	0.49
500 ppb	0.44	0.48	0.50
1000 ppb	0.45	0.50	0.49
LSD (*P=0.05*)[1]		0.06	

1. LSD = Least significant differences at the 5% significance level.

Table 7. Experiment 1a. Effect of SmartFresh at 0 ppb, 100 ppb, 250 ppb, 500 ppb and 1000 ppb for 2 hours at 20°C on the percentage incidence of rots in strawberry cv. Selva, followed by exposure to ethylene at 0.4 ppm for 24 hours plus 6 days at 5°C.

SmartFresh concentration ppb =parts per billion	Rots incidence (%)	
	Time (days at 5°C)	
	3	6
0 ppb	13.3	31.7
100 ppb	11.7	31.7
250 ppb	5.0	26.7
500 ppb	11.7	35.0
1000 ppb	6.7	25.0
LSD (*P=0.05*) comparing across rows[1]	18.7	
LSD (*P=0.05*) other	14.9	

1. LSD = Least significant differences at the 5% significance level.

Table 8. Experiment 1a. Effect of SmartFresh at 0 ppb, 100 ppb, 250 ppb, 500 ppb and 1000 ppb for 2 hours at 20°C on the rated colour of strawberry cv. Selva, followed by exposure to ethylene at 0.4 ppm for 24 hours plus 6 days at 5°C.

SmartFresh concentration ppb =parts per billion	Rated colour[1]		
	Time (days at 5°C)		
	1	3	6
0 ppb	2.2	2.3	2.1
100 ppb	1.9	2.6	2.2
250 ppb	2.2	2.5	1.9
500 ppb	1.8	2.4	2.1
1000 ppb	1.9	2.5	2.0
LSD (*P=0.05*) comparing across rows[2]	0.5		
LSD (*P=0.05*) other	0.7		

1. Rated colour %: Higher values represent darker colour fruit.
2. LSD = Least significant differences at the 5% significance level.

Table 9. Experiment 1a. Effect of SmartFresh at 0 ppb, 100 ppb, 250 ppb, 500 ppb and 1000 ppb for 2 hours at 20°C on the rated gloss of strawberry cv. Selva, followed by exposure to ethylene at 0.4 ppm for 24 hours plus 6 days at 5°C.

SmartFresh concentration ppb =parts per billion	Rated Gloss[1]		
	Time (days at 5°C)		
	1	3	6
0 ppb	2.3	2.3	2.3
100 ppb	2.2	2.2	2.3
250 ppb	2.3	2.3	2.4
500 ppb	2.3	2.2	2.3
1000 ppb	2.4	2.2	2.2
LSD (*P=0.05*) comparing across rows[2]	0.2		
LSD (*P=0.05*) other	0.2		

1. Rated gloss %: Higher values represent glossier fruit.
2. LSD = Least significant differences at the 5% significance level.

Table 10. Experiment 1a. Effect of SmartFresh at 0 ppb, 100 ppb, 250 ppb, 500 ppb and 1000 ppb for 2 hours at 20°C on the market quality of strawberry cv. Selva, followed by exposure to ethylene at 0.4 ppm for 24 hours plus 6 days at 5°C.

SmartFresh concentration ppb =parts per billion	Market quality[1]		
	Time (days at 5°C)		
	1	3	6
0 ppb	7.0	6.3	7.3
100 ppb	6.7	6.3	7.0
250 ppb	7.0	6.7	6.7
500 ppb	7.0	7.7	5.3
1000 ppb	7.3	6.7	5.7
LSD (*P=0.05*) comparing across rows[2]	1.3		
LSD (*P=0.05*) other	1.6		

1. Market quality: 1 equals the lowest quality and 10 highest quality field fresh.
2. LSD = Least significant differences at the 5% significance level.

Table 11. Experiment 2. Effect of SmartFresh at 0 ppb, 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C on the firmness of strawberry cv. Selva, after 7 days at 5°C .

SmartFresh concentration ppb =parts per billion	Firmness (kgf)		
	Time (days at 5°C)		
	2	4	7
0 ppb	0.48	0.50	0.42
250 ppb	0.49	0.52	0.45
500 ppb	0.51	0.58	0.45
1000 ppb	0.51	0.60	0.47
2000 ppb	0.53	0.58	0.47
LSD (*P=0.05*) comparing across rows[1]	0.07		
LSD (*P=0.05*) other	0.06		

1. LSD = Least significant differences at the 5% significance level.

Table 12. Experiment 2. Effect of SmartFresh at 0 ppb, 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C on the percentage incidence of rots in strawberry cv. Selva, after 7 days at 5°C.

SmartFresh concentration ppb =parts per billion	Rots incidence (%)	
	Time (days at 5°C)	
	4	7
0 ppb	6.7	6.8
250 ppb	8.3	5.0
500 ppb	5.0	6.7
1000 ppb	3.3	13.3
2000 ppb	6.7	6.7
LSD (*P=0.05*) comparing across rows[1]	17.4	
LSD (*P=0.05*) other	16.9	

1. LSD = Least significant differences at the 5% significance level.

Table 13. Experiment 2. Effect of SmartFresh at 0 ppb, 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C on the rated colour of rots of strawberry cv. Selva, after 7 days at 5°C.

SmartFresh concentration ppb =parts per billion	Rated colour[1] Time (days at 5°C)		
	2	4	7
0 ppb	1.9	2.6	2.3
250 ppb	1.7	2.5	2.3
500 ppb	2.1	2.5	2.3
1000 ppb	1.7	2.4	2.3
2000 ppb	2.0	2.4	2.1
LSD (*P=0.05*) comparing across rows[2]	0.3		
LSD (*P=0.05*) other	0.3		

1. Rated colour %: Higher values represent darker colour fruit.
2. LSD = Least significant differences at the 5% significance level.

Table 14. Experiment 2. Effect of SmartFresh at 0 ppb, 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C on the rated gloss of rots of strawberry cv. Selva, after 7 days at 5°C.

SmartFresh concentration ppb =parts per billion	Rated Gloss Time (days at 5°C)		
	2	4	7
0 ppb	2.6	1.7	2.0
250 ppb	2.2	1.5	1.9
500 ppb	2.7	1.7	2.0
1000 ppb	2.5	1.6	2.0
2000 ppb	2.5	1.7	1.2
LSD (*P=0.05*) comparing across rows[2]	0.8		
LSD (*P=0.05*) other	0.7		

1. Rated gloss %: Higher values represent glossier fruit.
2. LSD = Least significant differences at the 5% significance level.

Table 15. Experiment 2. Effect of SmartFresh at 0 ppb, 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C on the market quality of rots of strawberry cv. Selva, after 7 days at 5°C.

SmartFresh concentration ppb =parts per billion	Market quality[1] Time (days at 5°C)		
	2	4	7
0 ppb	8.0	6.3	6.7
250 ppb	6.3	6.7	5.0
500 ppb	8.0	6.3	6.0
1000 ppb	7.0	7.0	5.0
2000 ppb	7.0	5.7	6.0
LSD (*P=0.05*) comparing across rows[2]	1.6		
LSD (*P=0.05*) other	1.7		

1. Market quality: 1 equals the lowest quality.
2. LSD = Least significant differences at the 5% significance level.

Table 16. Experiment 2a. Effect of SmartFresh at 0 ppb, 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C on the firmness of strawberry cv. Selva followed by ethylene at 0.4 ppm for 24 hours plus 6 days at 5°C.

SmartFresh concentration ppb =parts per billion	Firmness (kgf)		
	Time (days at 5°C)		
	1	3	6
0 ppb	0.52	0.56	0.52
250 ppb	0.51	0.59	0.47
500 ppb	0.52	0.54	0.41
1000 ppb	0.54	0.59	0.46
2000 ppb	0.52	0.58	0.43
LSD (*P=0.05*) comparing across rows	0.06		
LSD (*P=0.05*) other	0.07		

1. LSD = Least significant differences at the 5% significance level.

Table 17. Experiment 2a. Effect of SmartFresh at 0 ppb, 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C on the percentage incidence of rots in strawberry cv. Selva followed by ethylene at 0.4 ppm for 24 hours plus 6 days at 5°C.

SmartFresh concentration ppb =parts per billion	Rots incidence (%)	
	Time (days at 5°C)	
	3	6
0 ppb	1.7	5.0
250 ppb	5.0	0.0
500 ppb	3.3	15.0
1000 ppb	5.0	8.3
2000 ppb	12.5	15.0
LSD (*P=0.05*) comparing across rows[1]	15.5	
LSD (*P=0.05*) other	14.3	

1. LSD = Least significant differences at the 5% significance level.

Table 18. Experiment 2a. Effect of SmartFresh at 0 ppb, 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C on the rated colour of strawberry cv. Selva followed by ethylene at 0.4 ppm for 24 hours plus 6 days at 5°C.

SmartFresh concentration ppb =parts per billion	Rated colour[1]		
	Time (days at 5°C)		
	1	3	6
0 ppb	2.0	2.4	2.2
250 ppb	2.0	2.6	2.3
500 ppb	2.0	2.5	2.3
1000 ppb	2.0	2.5	2.3
2000 ppb	2.0	2.4	2.4
LSD (*P=0.05*) comparing across rows[2]	0.2		
LSD (*P=0.05*) other	0.2		

1. Rated colour %: Higher values represent darker colour fruit.
2. LSD = Least significant differences at the 5% significance level.

Table 19. Experiment 2a. Effect of SmartFresh at 0 ppb, 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C on the rated gloss of strawberry cv. Selva followed by ethylene at 0.4 ppm for 24 hours plus 6 days at 5°C.

SmartFresh concentration ppb =parts per billion	Rated Gloss[1]		
	Time (days at 5°C)		
	1	3	6
0 ppb	2.6	1.7	2.0
250 ppb	2.7	1.6	2.1
500 ppb	2.5	1.7	2.1
1000 ppb	2.7	2.0	2.0
2000 ppb	2.6	1.8	2.0
LSD (*P=0.05*) comparing across rows[2]	0.6		
LSD (*P=0.05*) other	0.6		

1. Rated gloss %: Higher values represent glossier fruit.
2. LSD = Least significant differences at the 5% significance level.

Table 20. Experiment 2a. Effect of SmartFresh at 0 ppb, 250 ppb, 500 ppb, 1000 ppb and 2000 ppb for 4 hours at 2.5°C on the market quality of strawberry cv. Selva followed by ethylene at 0.4 ppm for 24 hours plus 6 days at 5°C.

SmartFresh concentration ppb =parts per billion	Market quality[1]		
	Time (days at 5°C)		
	1	3	6
0 ppb	6.3	6.7	5.3
250 ppb	7.7	6.3	6.0
500 ppb	7.3	5.7	6.0
1000 ppb	7.0	6.3	5.0
2000 ppb	7.3	6.3	5.3
LSD (*P=0.05*) comparing across rows[2]	2.2		
LSD (*P=0.05*) other	1.9		

1. Market quality: 1 equals the lowest quality and 10 highest quality: field fresh.
2. LSD = Least significant differences at the 5% significance level.

Table 21. Experiment 3. Effect of SmartFresh at 0 ppb, 15 ppb, 250 ppb and 500 ppb for up to 4 hours at 2.5°C on the firmness of strawberry cv. Selva after 7 days at 5°C.

SmartFresh concentration ppb =parts per billion	Firmness (kgf)
0 ppb	0.57
15 ppb	0.58
50 ppb	0.58
500 ppb	0.58
LSD (*P=0.05*)[1]	0.02

1. LSD = Least significant differences at the 5% significance level.

Table 22. Experiment 3. Effect of fumigation times 1 hour, 2 hours and 4 hours at 2.5°C of SmartFresh on the firmness of strawberry cv. Selva.

SmartFresh exposure time (hours)	Firmness (kgf)
1 hrs	0.58
2 hrs	0.58
4 hrs	0.58
LSD (*P=0.05*)[1]	0.01

[1.] LSD = Least significant differences at the 5% significance level.

Table 23. Experiment 3. Effect of ethylene at 1 ppm for 24 hours at 2.5°C on the firmness of strawberry cv. Selva.

Ethylene	Firmness (kgf)
Ethylene plus	0.58
Ethylene minus	0.58
LSD (*P=0.05*)[1]	0.01

[1.] LSD = Least significant differences at the 5% significance level.

Table 24. Experiment 3. Effect of storage time at 5°C on the firmness of strawberry cv. Selva.

Storage time (days)	Firmness (kgf)
2	0.60
4	0.58
7	0.56
LSD (*P=0.05*)[1]	0.01

[1.] LSD = Least significant differences at the 5% significance level.

Table 25. Experiment 3. Effect of SmartFresh at 0 ppb, 15 ppb, 250 ppb and 500 ppb for up to 4 hours at 2.5°C on the acceptable colour rating of strawberry cv. Selva after 7 days at 5°C.

SmartFresh concentration ppb =parts per billion	Acceptable colour rating
0 ppb	67.0
15 ppb	70.9
50 ppb	64.3
500 ppb	67.8
LSD (*P=0.05*)[1]	5.0

[1.] LSD = Least significant differences at the 5% significance level.

Table 26. Experiment 3. Effect of fumigation time 1 hour, 2 hours and 4 hours at 2.5°C of SmartFresh on the acceptable colour rating of strawberry cv. Selva.

SmartFresh exposure time (hours)	Acceptable colour rating
1 hrs	67.6
2 hrs	69.3
4 hrs	65.6
LSD (*P=0.05*)[1]	4.4

[1.] LSD = Least significant differences at the 5% significance level.

Table 27. Experiment 3. Effect of ethylene at 1 ppm for 24 hours at 2.5°C on the acceptable colour rating of strawberry cv. Selva.

Ethylene	Acceptable colour rating
Ethylene plus	67.9
Ethylene minus	67.1
LSD (*P=0.05*)[1]	3.7

[1] LSD = Least significant differences at the 5% significance level.

Table 28. Experiment 3. Effect of storage time at 5°C on the acceptable colour rating of strawberry cv. Selva.

Storage time (days)	Acceptable colour rating
2	78.0
4	71.0
7	53.5
LSD (*P=0.05*)[1]	4.6

[1] LSD = Least significant differences at the 5% significance level.

Table 29. Experiment 3. Effect of SmartFresh at 0 ppb, 15 ppb, 250 ppb and 500 ppb for up to 4 hours at 2.5°C on the percentage incidence of rots in strawberry cv. Selva after 7 days at 5°C.

SmartFresh concentration ppb =parts per billion	Rots incidence (%)
0 ppb	14.5
15 ppb	11.1
50 ppb	14.8
500 ppb	15.7
LSD (*P=0.05*)[1]	4.8

[1] LSD = Least significant differences at the 5% significance level.

Table 30. Experiment 3. Effect of fumigation time 1 hour, 2 hours and 4 hours at 2.5°C of SmartFresh on the percentage incidence of rots in strawberry cv. Selva.

SmartFresh exposure time (hours)	Rots incidence (%)
1 hrs	11.6
2 hrs	15.6
4 hrs	14.8
LSD (*P=0.05*)[1]	4.1

[1] LSD = Least significant differences at the 5% significance level.

Table 31. Experiment 3. Effect of ethylene at 1 ppm for 24 hours at 2.5°C on the percentage incidence of rots in strawberry cv. Selva.

Ethylene	Rots incidence (%)
Ethylene plus	13.3
Ethylene minus	14.8
LSD (*P=0.05*)[1]	3.6

[1] LSD = Least significant differences at the 5% significance level.

Table 32. Experiment 3. Effect of storage time at 5°C on the percentage incidence of rots in strawberry cv. Selva.

Storage time (days)	Rots incidence (%)
4	9.7
7	18.3
LSD (*P=0.05*)[1]	3.6

[1] LSD = Least significant differences at the 5% significance level.

Table 33. Experiment 4. Effects of ethylene at 1 ppm for 21 hours and SmartFresh concentration on the firmness of strawberry cv. Selva after 3, 6 and 9 days at 5°C.

SmartFresh Concentration (ppb = parts per billion)	Firmness (kgf)	
	Ethylene	
	Minus	Plus
0 ppb	0.57	0.58
15 ppb	0.60	0.57
LSD (*P=0.05*)[1]	0.02	

[1] LSD = Least significant differences at the 5% significance level.

Table 34. Experiment 4. Effect of SmartFresh concentration, fumigation temperature and storage time on the firmness of strawberry cv. Selva after 3, 6 and 9 days at 5°C.

Storage time (days at 5°C)	Firmness (kgf)			
	SmartFresh concentration			
	0 ppb		15 ppb	
	Fumigation temperature (°C)			
	2.5°C	20°C	2.5°C	20°C
Day 3	0.56	0.54	0.58	0.57
Day 6	0.58	0.57	0.57	0.59
Day 9	0.58	0.60	0.62	0.58
LSD (*P=0.05*)[1]	0.03			

[1] LSD = Least significant differences at the 5% significance level.

Table 35. Experiment 4. Effect of SmartFresh concentration, fumigation temperature and storage time on the percentage incidence of acceptable colour of strawberry cv. Selva after 3, 6 and 9 days at 5°C.

Storage time (days at 5°C)	Acceptable colour incidence (%)			
	SmartFresh concentration			
	0 ppb		15 ppb	
	Fumigation temperature (°C)			
	2.5°C	20°C	2.5°C	20°C
Day 3	92.1	96.7	92.1	97.7
Day 6	85.2	91.5	91.5	95.4
Day 9	64.8	86.1	73.2	86.1
LSD (*P=0.05*) comparing down a column[1]	8.5			
LSD (*P=0.05*) other	8.2			

[1] LSD = Least significant differences at the 5% significance level.

Table 36. Experiment 4. Effect of SmartFresh concentration, fumigation temperature and storage time on the percentage incidence of rots in strawberry cv. Selva after 3, 6 and 9 days at 5°C.

Storage time (days at 5°C)	Rots incidence (%)			
	SmartFresh concentration			
	0 ppb		15 ppb	
	Fumigation temperature (°C)			
	2.5°C	20°C	2.5°C	20°C
Day 3	4.2	7.0	3.3	8.0
Day 6	9.2	15.9	5.4	11.4
Day 9	7.9	18.5	12.5	21.8
LSD (*P=0.05*) comparing down a column[1]	8.0			
LSD (*P=0.05*) other	7.9			

[1.] LSD = Least significant differences at the 5% significance level.

8. PLATES

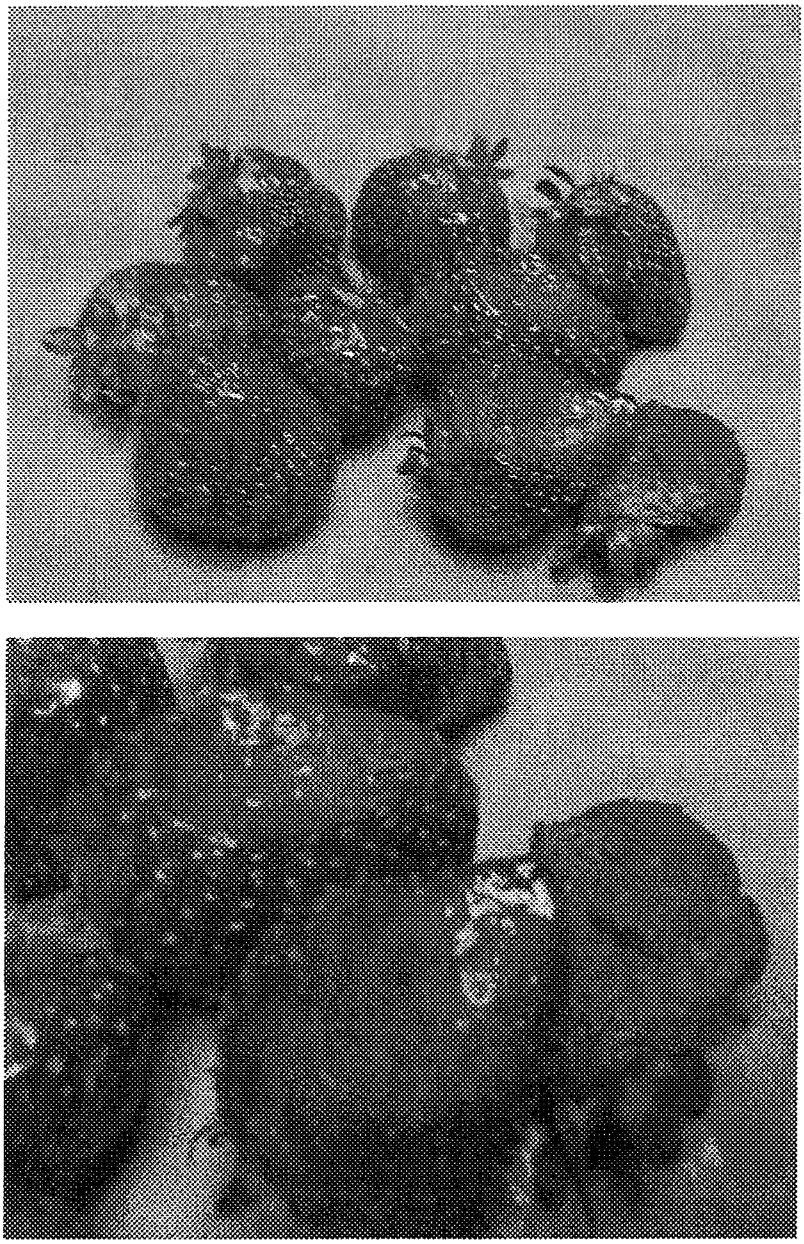


Plate 6. Rots observed in experiment 1, which were typical of the rots seen in all of the experiments.

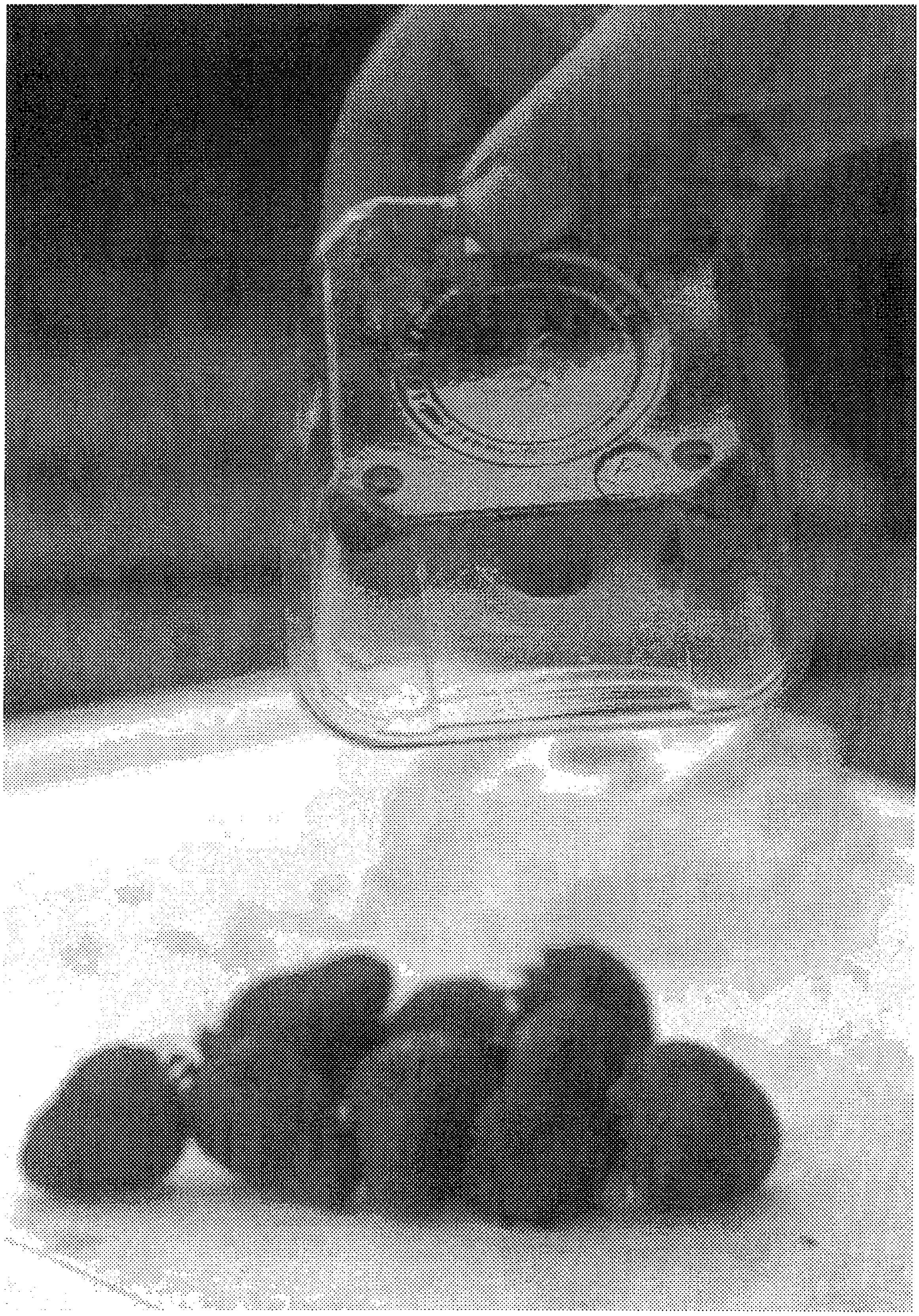


Plate 7. The plastic punnets used here appeared to contribute significantly to the reduced storage life of strawberries. Squeezing the fruit to fit into the base of the punnet damaged the fruit and provided sites for rot development. The photograph above shows that the fruit was so tightly packed that when the punnet was inverted, the fruit did not fall out.