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A literature review

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A LITERATURE REVIEW

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SUMMARY

This literature review is only a brief inventarisation of the possible methods to overcome the problems which occur during storage and transportation of fresh strawberies. Strawberries are a very popular fruit, which is produced in large quantities in many countries all over the world. They are very susceptible to mechanical and fungal damage and normally store only up to 7 days. In California CA storage and transportation is practiced on a commercial base. Rot is the main factor of loss of quality, of which *Botrytis cinerea* causes the greatest damage.

Ideally strawberries should be cooled immediately after harvest. Recommended CA conditions are 15-20% CO2, 5-10% O2 and 90% RH. Several adaptations of MA and CA storage systems may prolonge keepability and preserve quality. Other gases have been added, such as ozon, carbon monoxide, laughing gas, chlorine dioxide and very high nitrogen concentrations, and promising results have been obtained. Also hygroscopic material can be added to MA packs to lower RH, which may result in reduced decay. Hypobaric storage is a technique, which seems to have good effects on quality preservation of even soft strawberry varieties, although some loss of taste and flavour occurs. However, the method is not very practical. Biological control of postharvest pathogens is another aspect that is under extensive research. Natural volatiles have shown to be antifungal, as have secondary plant metabolites. Especially the use of bacteria and yeasts looks very promising, although the persistence of the organisms may influence the acceptability to registration authorities.

If not a single method is able to preserve quality and prolonge storage life of strawberries, maybe a combination of methods is. However, some techniques can affect each other negatively. To achieve success is necessary and the described methods can be very helpful.

TABLE OF CONTENTS

1 INTRODUCTION

Strawberries (*Fragaria ananassa* Duchesne) are very much appreciated by consumers. They are a tasteful and aromatic fruit and contain a lot of vitamin C. Some production figures are given in table 1.1. In 1985 13,900 MT strawberries were sold through the auction with a value of 69.5 million guilders in the Netherlands. In the same country 60% of the produce is fresh consumption (Anon., 1986). Especially in the USA strawberries are transported over long distances from the growing areas in California to the urban centres on the East coast.

Table 1.1. Some production figures of strawberries in 1990 (Anon., 1991).

Region	Production (x MT)
World	2,357,756
USA	570,302
Japan	215,000
Europe	1,075,713
Poland	241,284
Spain	197,950
Netherlands	26,000

Strawberries are a very vulnerable crop and normally they store only up to 7 days. In general the strawberries are cooled down to the advised transportation temperature directly after harvest. If the intransit time is less than a day, the temperature can be 15°C, but if this time is more than three days, the temperature should be 0-2°C. RH in all circumstances should be 90%. In California dry ice is added during transportation. This method does not only cool down the produce, but the CO2 concentration rises, which slows down decay. Also in California CA storage is practiced on a commercial base. Storage life can be prolonged with 10-14 days. For storage and transportation over long distances specific varieties suit best. They are firmer and less vulnerable and suffer less from mechanical and fungal damage. A disadvantage of these varieties is that they have less taste and flavour (Anon., 1986).

Despite the careful handling the quality and keepability of fresh strawberries is often insufficient. Rot is the main factor of loss of quality, but loss of taste and aroma also play a role. Especially during storage and transportation of varieties meant for fresh consumption big losses can occur. Consumers accept only minor damage. Strawberries meant for processing may have some more damage.

This litterature study gives a brief inventarisation of the problems related with transportation and storage of fresh strawberries and the methods, which can be used or need investigation to reduce harm. Special attention is paid to the control of fungal diseases, which cause the greatest damage. A far more extended study can be made, since much research is done on this subject and a lot of litterature is available. However, for the moment only a preliminary overview of the matter is prefered, which can be a basis for future research. In the following chapters the main problems which appear during handling will be described. Next the ways of handling and transportation will be mentioned. Furthermore alternative methods of preserving quality and prolonging storage life will be discussed. This will lead to some recommendations for future research.

2 MAIN PROBLEMS

Most quality characteristics can differ a lot between varieties. This accounts especially for taste, keepability and appearance (Schaik *et al.*, 1988). The quality of strawberries can be devided in outer and inner criteria. The outer criteria are (Arts, 1985; Ryall and Pentzer, 1982):

- colour;
- presence of caps (calyx);
- freshness; this includes sufficient moisture content, no shrinkles and no over-ripeness;
- size and shape;
- absence of damage from bruising, crushing and mould;
- firmness.

The most important inner characteristics are (Arts, 1985):

- taste;
- texture;
- nutritional value;
- inner colour;
- flavour;
- aroma.

The main problems which occur during harvest and handling of strawberries are damage from bruising, crushing and mould, which shorten the storage period. During storage or transportation loss of taste and aroma can appear. The mechanical damage of bruising and crushing can be

avoided by minimal touching the fruit with the fingers during picking. Also overloading the package,
which causes pressing of the fruits, should be avoided (Smith, 195?). The physical damage can also act as an entrance for pathogens. In strawberries *Botrytis cinerea* is causing the greatest damage. *Mucor piriformis* is also acting as an important pathogen.

Infection of strawberries by *B. cinerea* results in a brown discolouration of the infected tissue which usually remains relatively firm. The surface of the rotted tissue is initially covered by a white to greyish mycelium which eventually becomes covered by a mat of grey conidiophores bearing the conidia. The fungus can exist as a saprophyte in strawberry plantations and has been observed to sporulate on dead leaves and debris, and therefore it is not surprising that airborne conidia are always present prior to and during the flowering and fruiting season. The frequent isolation of *B. cinerea* from the stem end of ripe, healthy fruit and the high percentage of these fruits which rot under moist conditions indicate considerable latent infection. Thus at harvest, strawberries will be contaminated by conidia of *B. cinerea* on the fruit surface as well as latent infections being present at the stem end. *B. cinerea* is able to grow and infect strawberries at temperatures as low as 0°C and thus its development is only delayed by rapid cooling and storage of fruit under recommended commercial conditions (c. 2°C) (Dennis, 1983).

Infection of strawberries by *M. piriformis* results in a water-soaked appearance of the infected area, which is very soft and very rapidly becomes covered with asexual sporangiophores and sporangia. As with *B. cinerea*, environmental conditions during flowering and fruiting greatly influence the degree of contamination of the fruit and subsequent postharvest infection. *M. piriformis* only infects ripe fruits, so the increase in inoculum in plantations is limited to the latter part of the season. Hence late season fruit shows a greater contamination by *M. piriformis* and the fungus is generally more important in causing postharvest rotting of fruit harvested towards the end of the season. During storage and distribution, strawberries become infected from viable propagules, spores and mycelial fragments, on the surface of the fruit and subsequent spread occurs via fruit contact. Infection occurs at temperatures as low as 0°C (Dennis, 1983).

According to Arts (1985) during storage changes in taste and flavour occur. Storage consequently leads to a loss of aroma, which has a negative effect on taste. After 10 days storage at 1.7°C a loss of aroma is measured and after 20 days all aroma is disappeared. Arts (1985) mentions that other researchers measured a loss of aroma after only 4 or 5 days.

Relatively firm varieties have a longer keepability, but generally have less taste and flavour than soft varieties. However, softness results in a higher susceptibility to mechanical and fungal damage, which shortens keepability (Schaik, 1987).

3 HANDLING

In this chapter will be discussed in what way strawberries should be handled after harvest and during storage and distribution period.

3.1 Cooling and pre-cooling

During the harvest period the air temperature can rise very high. On a sunny day the fruit temperature can be even higher, because of the dark colour. Therefore it is important to move the harvested produce as soon as possible to a cool place (Diepen, 1986). Often the strawberries cannot be transported immediately to the auction or wholesale market so they have to stay overnight or over the weekend at the farm. In this case it is advised to cool the strawberries mechanically to 3°C (Diepen, 1986).

Ideally it would be the best thing to have a so called closed cool chain from the grower till the consumer. Cooling has a very good effect on the preservation of the quality (Diepen, 1986):

- reduction of rot;
- no dark colouring;
- less dark spots, caused by bruising;
- general quality after 1-2 days is better than of non-cooled strawberries;
- because of cooling the fruits have a temporary gloom, but when this disappears they are brighter than non-cooled strawberries.

3.2 CA and MA

In the nineteen-thirties solid carbon dioxide, dry ice, began to be used for the commercial transport of soft fruits. It was at that time considered that the inclusion of blocks of dry ice at roof level in a closed insulated rail container would provide refrigeration for the fruit in transit. Research was conducted to find out under which conditions the fruit was really transported. It was found that the temperature was lowered only slightly, while a concentration of 15-20% carbon dioxide was built up in the atmosphere. It was confirmed that it was the enrichment of the air in the container with carbon dioxide that had a beneficial effect upon travelling performance rather than the rather small degree of cooling achieved by inclusion of dry ice (Smith, 195?).

Nowadays strawberries are loaded on pallets and covered with polyethylene film for transport and CO2 is injected (Browne *et al.*, 1984). A lot of research has been focused on the CA storage and MA packaging of strawberries (Beer *et al.*, 1989; Browne *et al.*, 1984; Harvey, 1982). High CO2 concentrations of 10 to 30% give the best keepability. The respiration rate of the fruits is slowed down and the activity of decay-causing organisms is reduced. CO2 concentrations over 20% stimulate ethanol production and cause off-flavour. Low O2 concentrations can give the same effects as high CO2 (Hardenburg *et al.*, 1986). Kader (1989) gives the following recommendations. A level of 5-10% O2 and 15-20% CO2 are benificial, respiration rate is reduced, firmness is retented and decay is reduced. Injuries occur at levels of <2% O2 and >25% CO2, causing off-flavours and brown discolouration of strawberries.

4 ALTERNATIVE TECHNIQUES FOR PROLONGING KEEPABILITY AND PRESERVING QUALITY

In this chapter alternative techniques will be discussed, which can help to prolonge keepability and preserve quality. First attention will be given to adaptations of MA and CA storage systems. Than hypobaric storage will be mentioned. At last several methods of biological control of postharvest pathogens will be discussed.

4.1 Adaptations of MA and CA storage systems

Good results may be obtained by adding other gases to the atmosphere around the fruits. Research was carried out with two varieties at 15°C. Ozon was added in concentration of 4 to 350 mg/m3. Under these circumstances 20 mg/m3 gave a remarkable reduction of decay and a good quality was preserved compared with strawberries kept in normal air. Lower ozon concentrations gave no effect and higher concentrations gave off-flavours (Berger and Hansen, 1965).

Mechanically harvested strawberries meant for processing were stored at 24°C for 72 and 120 hours in atmospheres containing acetaldehyde (Aa) with and without prior dipping in 0 to 1.5% acetaldehyde solutions. Aa atmospheres and a combination of atmospheres and dips were most effective in maintaining visual colour, freedom from browning and product acceptability. However, an inhibitory effect of mould was not found (Morris *et al.*, 1979). This single method is not suitable for fresh market strawberries.

Woodruff (1977) states that where pathological disorders are the limiting factor in the product's storage life, conventional modified atmospheres usually have marginal, if any, benefit. Therefore he added carbon monoxide to atmospheres with elevated CO_2 and reduced O_2. Decay was inhibited of many fruits, such as grapes, peaches, nectarines and blueberries. However, not all applications of carbon monoxide to products have been promising. Some severe physiological disorders have been observed as well. Although further research is needed, use of carbon monoxide in short-term transit situations for fruits seems attractive.

Other research with alternative modified atmospheres showed that adding of extra N_2 had a more beneficial effect than standard modified atmospheres with elevated CO_2 (upto 20%). An atmosphere of 0.5% CO_2, 1% O_2 and c. 98% N_2 gave only 20% decay after 10 days storage at 4°C, while the taste and flavour of the healthy strawberries was very good. In other atmospheres with lower N_2 and higher O_2 and CO_2 concentrations strawberries had at least 35% decay and taste and flavour were poorer (Hansen, 1967).

Blueberries were stored in modified atmospheres in polyfilms. The film packages reduced moisture loss, but increased decay compared with a control. To control decay the contents were fumigated with chlorine dioxide. This was done by putting sachets of chlorine dioxide gas generators inside the packages. A disadvantage of fumigation was that moisture losses increased compared with film packages without chlorine dioxide (Ahmedullah *et al.*, 1989). Fumigation with chlorine dioxide might also reduce decay of MA packed strawberries.

In France research is carried out with laughing gas or nitrous oxide. Pallets with fresh produce are covered with plastic film and laughing gas is brought in (Kooten, pers. comm.). The gas is an ethylene antagonist, but what is more important in relation with strawberries are the fungistatic effects (Gouble *et al.*, 1994) More information is needed to find out if this technique is as interesting as it seems.

Apart from the gases that play a role in quality preservation also relative humidity is of importance. In CA or MA relative humidity is usually very high, 95-100%. These conditions are very favourable for fungal growth which causes decay of strawberries. Lowering relative humidity may reduce fungal growth. However a too low relative humidity can cause outdrying of the strawberries, which shows as wrinkling and shrinkage (Arts, 1985). In CA storage relative humidity can be regulated relatively easy with some technical adaptations. In MA package this is more difficult. Rodov *et al.* (1994) added salt (NaCl) to MA packed to bell peppers. The relative humidity was lowered and decay reduced. A model was developed in which the dynamics of CO_2, O_2 and RH could be predicted.

4.2 Hypobaric storage and transportation

Another form of storing and transporting agricultural commodity is called hypobaric storage or transportation. It consists of placing the commodity in an environment in which pressure, air temperature and humidity are precisely controlled. In addition, the rate at which the air in the storage environment is changed is closely regulated. No gas other other than air need be supplied in a hypobaric system, whereas in modified and controlled atmosphere storage, other gases are required. The total pressure within the hypobaric chamber is important, since the O_2 level is directly proportional to that pressure. For example, if a chamber is operated at one-tenth of an atmosphere (76 mm Hg) rather than at normal atmospheric pressure (760 mm Hg), the partial pressure of O_2 is, likewise, approximately 1/10 of normal (Jamieson, 1980).

A feature of hypobaric storage is 'out-gassing'. All perishable commodities produce CO_2 and consume O_2, so that CO_2 escapes and atmospheric O_2 enters the commodity. Other gases and volatiles, which have an adverse effect on storage life are also producec, such as ethylene and ethanol. Since these gases are present in much higher concentrations inside than in the surrounding atmosphere, they are forced out, thus reducing their adverse effect on storage life (Jamieson, 1980).

Hypobaric storage has been tried on strawberries. They were stored at several pressures, 95% RH and 1.1°C. After 9, 14, 18 and 21 days the strawberries were removed from storage and evaluated for colour, gloss, stem condition, firmness and percentage of fruit having fungal growth. Also the shelf life was determined. Therefore the strawberries were placed in shelf life storage at 1.1°C at atmospheric pressure and evaluated again after 2 and 5 days. After every storage and shelf-life interval, the hypobaric fruit was rated superior to the control, which was stored at normal refrigeration. The lowest percentage of fungus, mainly grey mould rot , after 21 days was observed on the strawberries stored at 10 mm Hg. The soft variety used in this research can be stored hypobarically for 21 days and has a subsequent shelf life of 4-5 days (Jamieson, 1980). Also other varieties, which store 5-7 days in cold storage, can be stored 21-28 days in hypobaric storage (Haard and Salunkhe, 1975).

A disadvantage of hypobaric storage can be that a loss of taste occurs, which seems to be caused by internal damage (Schaik, pers. comm.). Hypobaric transportation can also be not practical, since the necessary equipment is very big and consumes a lot of energy.

4.3 Biological control of postharvest pathogens

A lot of research is carried out to find out which biological agents can control postharvest pathogens of many commodities. Several promising outlooks will be mentioned. Future research will be needed to investigate wether biological control methods against the main postharvest pathogens of strawberries can be developed or not.

Several volatile compounds present in ripening fruit were shown to inhibit three important postharvest decay fungi and prolonge shelf life when present in the headspace gas surrounding the fruit. The heterocyclic compound furaneol [2,5-dimethyl-4-hydroxy-3(2*H*)-furanone] is a major constituent of many fruits, including strawberries and blueberries, and was found to be moderately inhibitory to fungi. Several closely-related furan ring compounds were examined for antifungal activity on intact strawberry and blueberry fruit and against isolated cultures of *Alternaria alternata*, *Botrytis cinerea* and *Colletotrichum gloeosporioides*. Of the compounds tested, 2(5*H*)-furanone, γ-valerolactone and α-angelicalactone were the most antifungal. Fungal toxicity appears to be at least partially related to volatility, as the more volatile compounds were generally the mos antifungal . At higher concentrations several of the compounds caused an unusual bleaching of the fruit, with the bleached fruit appearing to have lost some structural rigidity indicating membrane damage. It is possible that by controlling release rate of these compounds effective fungal control can be achieved without excessive fruit damage (Vaughn and Ehlenfeldt, 1993).

Smid *et al.* (1994) tested several essential oil components for antifungal activity towards *Penicillium hirsutum* and *P. allii* on flower bulbs. Carvone, cuminaldehyde, perillaldehyde, cinnamaldehyde, salicylaldehyde and benzaldehyde were selected as the most potent inhibitors of in vitro growth. Storage of tulip bulbs in an atmosphere containing cuminaldehyde, perillaldehyde, salicylaldehyde or carvone, resulted in a significant reduction of the outgrowth of the natural

Penicillium infection. Under these conditions, no significant antifungal effect of cinnamaldehyde was observed. These secondary plant metabolites may also be tested on antifungal activity on pathogens of strawberries. Anyway consumers may hesitate to buy fresh fruits, which is contaminated with these metabolites, since they fear any harmful reaction which they might have on man. Therefore registration authorities can uphold the use of those metabolites in practice.

Bacteria and yeast isolates have been tested as biocontrol agents against *Botrytis cinerea* and *Penicillium expansum* on apples and pears by Kampp (1994). A bacterium, *Erwinia* sp. strain A-5, provided complete protection against *B. cinerea* on apples. A yeast, *Rhodotorula* strain A-60 was effective against *P. expansum* at low temperatures and also reduced rotting at higher temperatures. The efficiency of the two antagonists was lower when they were tested against the pathogens on pears. Although strain A-5 produced antibiotic metabolites in vitro, it was not possible to demonstrate the role of these metabolites in biocontrol on the fruit.

Also Epton *et al.* (1994) showed that bacteria and yeasts selected from the surface of fruit and vegetables are able to inhibit the growth in vitro, and frequently in vivo, of common storage pathogens. Storage trials with whit cabbage showed that some bacteria were able to reduce losses caused by the postharvest pathogens *B. cinerea* and *Alternaria brassicicola* in commercial cold stores, and in some instances the level of control achieved was equivalent to the level of control obtained by the use of chemical fungicides. Epton *et al.* (1994) state that the persistence of the applied organisms during storage may relate to their effectiveness, and may also influence the acceptability of agents to registration authorities.

5 CONCLUSIONS AND RECOMMENDATIONS

The quality and keepability of fresh strawberries is often insufficient. The main cause of loss of quality is decay by the postharvest pathogens *Botrytis cinerea* and *Mucor piriformis*. Loss of taste and flavour also occurs. Relatively firmer varieties which are less susceptible to mechanical and fungal damage than soft varieties generally also have less taste and flavour.

Cooling and pre-cooling can preserve quality better and prolonge storage life with 1-2 days to 5-7 days. CA storage and MA packaging also have a beneficial effect. The following recommendations are given: a level of 5-10% $O2$ and 15-20% $CO2$ gives the best keepability, respiration rate is reduced, firmness is retented and decay is reduced. Still these methods are not sufficient to preserve quality of strawberries long enough. Especially decay forms a problem.

Therefore other, alternative, methods need to be investigated. Other gases can be added to the atmosphere. Research has been carried out with ozon, carbon monoxide, laughing gas, chlorine dioxide and very high nitrogen concentrations and promising results have been obtained. Also adding of hygroscopic material in side MA packages can reduce decay. These methods certainly need to be taken in consideration if research will be carried out in the future.

A totally different method is hypobaric storage. With this method the O2 concentration is very low and gases which have an adverse effect on the quality of strawberries, such as ethylene and ethanol, enter the atmosphere from the fruits. This method seems to work very good, although further research is needed to avoid loss of taste and flavour. However, hypobaric seems not very suitable for transportation since the equipment is very big and consumes a lot of energy.

Another aspect that gets much attention in research is biological control of postharvest pathogens. Natural volatile furan compounds have shown to be antifungal against several pathogens on strawberries, such as *B. cinerea.* Also secondary plant metabolites, such as aldehydes, have proved to be antifungal, but not on strawberries yet. The use of bacteria and yeasts against pathogens seems very promising. Several pathogens on many vegetable and fruits species can be controlled with bacteria and yeasts, often as good as with chemicals. With help of genetic manipulation probably very good results will be obtained with biological control agents in the future, although the persistence of the organisms may influence the acceptability to registration authorities.

If not a single method is able to preserve quality and prolonge storage life of strawberries, maybe a combination of methods is. However, it is very well possible that the use of several techniques at the same time affect each other negatively. For example, carbon monoxide can have an inhibiting effect on the control of a pathogen by a bacteria or yeast. To achieve success much research is necessary and the methods described above can be very helpful in this research.

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