STRAWBERRY HANDLING IN QUEBEC

BY

YVES LEPINE

A thesis submitted to the Faculty of Graduate Studies
and Research in partial fulfillment of the
requirements for the degree of
Master of Science

Department of Agricultural Engineering
Macdonald College
McGill University
Montréal

ABSTRACT

YVES LEPINE M.SC. (Agr. Eng)

STRAWBERRY HANDLING IN QUEBEC

The shelf life of strawberries grown in Québec is very short and does not extend more than two days. Yet strawberries from California have a shelf life of more than a week. In a literature review, we studied the many factors influencing shelf life. Variety, maturity, cultural practices, methods of harvest and post harvest handling were all factors influencing shelf life. Given a well managed field with adequate harvesting method, we found that precooling and controlled atmosphere (CA) storage were the factors that contributed most to maintain the quality of the berries. Experiments were conducted to evaluate the influence of regular storage (RA) and CA storage on shelf life. The CA consisted of a gas mixture composed of 16 +/- 1.5% CO_2, 20 +/- 1% O_2 and 64 +/- 2% N_2. After 10 days of storage at 5 °C and 2 additional days where berries were kept successively at 10 °C or at 22 °C for periods of 12 hours, 80% of the strawberries stored in CA were sound compared to 55% for those stored in RA. CA storage had no effect on quality parameters such as soluble solids, acidity and moisture content. An increase in the firmness of the skin and the flesh was observed.

An experiment was carried out to evaluate the effects of short exposure to high CO_2 concentrations on strawberry quality. While being precooled, some strawberries were left in sealed containers

where CO_2 concentrations were over 80% initially. These CO_2 concentrations were decreased from 80% to about 55%. No off flavors or foul odors were observed after a two hour exposure to high CO_2 concentrations . This treatment did not reduce decay but did increase the firmness of the flesh.

To verify the effectiveness of CA in preventing the growth of fungi, spoiled strawberries inoculated with Botrytis cinerea were placed among freshly harvested berries stored in CA or in RA. We noted CA to be effective in preventing the growth of Botrytis cinerea from a molded strawberry to berries located next to it (nesting).

Given a widespread use of precooling, the use of CA could easily double the shelf life of strawberries. This will also lead to reduction in losses and provide an opportunity to explore export market to the neighbouring states or provinces.

RESUME

YVES LEPINE M.Sc. (Agr. Eng.)

LA MANUTENTION DES FRAISES AU QUEBEC

Les fraises cueillies au Québec ne se conservent pas plus de deux jours. Si l'on considère que les fraises importées de Californie se conservent plus d'une semaine, la période de conservation des fraises du Québec est très courte. Une revue de la littérature a permis de déteminer que la variété et la maturité des fraises, les pratiques culturales, les méthodes de récoltes et la manutention suivant la récolte étaient les facteurs qui affectaient le plus la conservation de la fraise. En supposant une bonne gestion des champs et des méthodes de récolte adéquates, le prérefroidissement et l'entreposage en atmosphère controlée (AC) sont les facteurs qui contribuent le plus à maintenir la qualité des fraises.

Des expériences ont permis de comparer l'entreposage en chambre froide et en atmosphère contrôlée. L'entreposage en AC a réduit les pertes dues aux moisissures sans affecter significativement les paramètres d'évaluation de la qualité telles que le pourcentage de solides en solution, l'acidité, et le contenu en eau. La chair des fraises entreposées en AC etait plus ferme. Apres 10 jours d'entreposage à 5 ^{o}C suivis de 2 jours où les fraises ont tour à tour été entreposées à 10 ^{o}C et à 22^{o}C pour des périodes de 12 heures, 80% des fraises entreposées en AC étaient vendables comparativement à 55% pour les fraises entreposees en chambre froide.

L'influence sur la qualité des fraises d'une courte exposition à des concentrations de CO_2 élevées a été évaluée. Au cours du prérefroidissement, des fraises placées dans des contenants hermétiques ont été exposées à des concentrations de CO_2 qui étaient initialement de 80% Au cours du prérefroidissement, on a laissé la concentration en CO_2 diminuer à 55% . Aucun arrière gout ou odeur douteuse n'a été observé après une exposition de deux heures à ces concentrations. Ce traitement n'a pas amélioré la conservation des fraises, ni augmenté la fermeté de la chair.

Un mélange de gaz comprenant 16 +/- 1.5% CO_2, 20 +/-1% O_2 et 64 +/2 % N_2 s'est révélé efficace dans la prévention de la croissance du <u>Botrytis cinerea</u> d'une fraise moisie aux fraises voisines. Le prérefroidissement et l'entreposage en AC permetttent de facilement doubler la période de conservation des fraises fraîches.

Une manutention améliorée des fraises permettra une meilleure conservation ce qui réduits de manière significative les pertes sur le marché local et rends possible l'exportation vers les provinces et états voisins.

ACKNOWLEDGEMENTS

The author would like to thank Dr. G.S.V. Raghavan, Professor Agricultural Engineering , for his encouragement in completing this study and for his patience in editing the many versions of the manuscripts.

The contributions of Messrs. Yvan Gariépy, Gilles St Pierre, Robert Houde, Jean Simon Blais, Pierre Langlois, P. Laplaine, Peter Alvo are gratefully acknowleuged. Supports from the Department of Agricultural Engineering, Entomology, Plant Science, Food Science and Microbiology are also deeply appreciated. We would like to thank in particular Dr. R. Knowles, Dr. D. Buszard, Dr. Reeleder, Dr. W.D. Marshall, Dr. J. MacFarlane and Dr. R. Kok.

The author would like to thank further his friends and relatives, in particular, Mr. Gérald Lafleur, Mr. Serge Poirier, Miss Ghislaine Lavertu, Miss Monique Marquis and Mr. and Mrs. Rémi Lépine for their support and advice.

This work has been an opportunity to develop new skills and to discover the hidden potentials of many persons. The benefits and the results of this work can not all be described in the following pages but some of the best part is presented.

Last, but not least, I would like to thank Natural Science and Engineering Research council and Agriculture Canada for the financial support through their grant programs.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I - INTRODUCTION

Canadian strawberry production has increased sharply since ten years. To deal with the surplus created, new markets must be found nationwide requiring transport to farther distances. Transport to longer distances needs improved conservation and handling techniques. In Québec, strawberries typically have a shelf life of two days or less which is too short for successful marketing outside the province. Although shelf life is first related to the cultivar characteristics, postharvest handling methods such as precooling and controlled atmosphere storage are as important in maintaining fruit quality. The adaptation of better post harvest handling techniques should lead to reduction in losses and a better quality product to the consumers.

1.1 The Strawberry Industry.

Strawberries are grown throughout the world from the arctic regions to the tropics. The United States, Japan, Mexico and Poland are the largest strawberry producers (Table 1.) (Childers, 1980). In the late seventies, Canadian production represented 1.8% of the world production.

Table 1. Approximate world production of strawberries in the late seventies.

Country	Production (X 1000 tonnes)	Country	Production (X 1000 tonnes)
United States	224	Denmark	11
Japan	115	Norway	10
Mexico	110	Spain	8
Poland	100	Greece	5
Italy	74	New Zealand	5
France	57	Australia	3
Yugoslavia	56	Finland	3
Germany (E&Fr)	49	Israel	2
Netherlands	32		
Bulgaria	30		
Belgium	25		
Hungary	21		
Canada	19		
Czechoslovakia	15		

Adapted from Childers, 1980.

Strawberry production in Canada is concentrated in Québec (33%), Ontario (23%) and British Columbia (29%) (Berthelot, 1984). Since 1971, Québec strawberry production has nearly doubled. In 1986, production raised to 8,984 tonnes and had a farm value of $ 9.55 million. This production covered 75% of the provincial consumption of fresh strawberries (Figure 1). Because it is very dependent on weather conditions, annual local strawberry production is unpredictable (Figure 2). For instance, yields were down to 3.4 tonnes/ha in 1981 and rose by 35% to 4.6 tonnes/ha in 1982. These

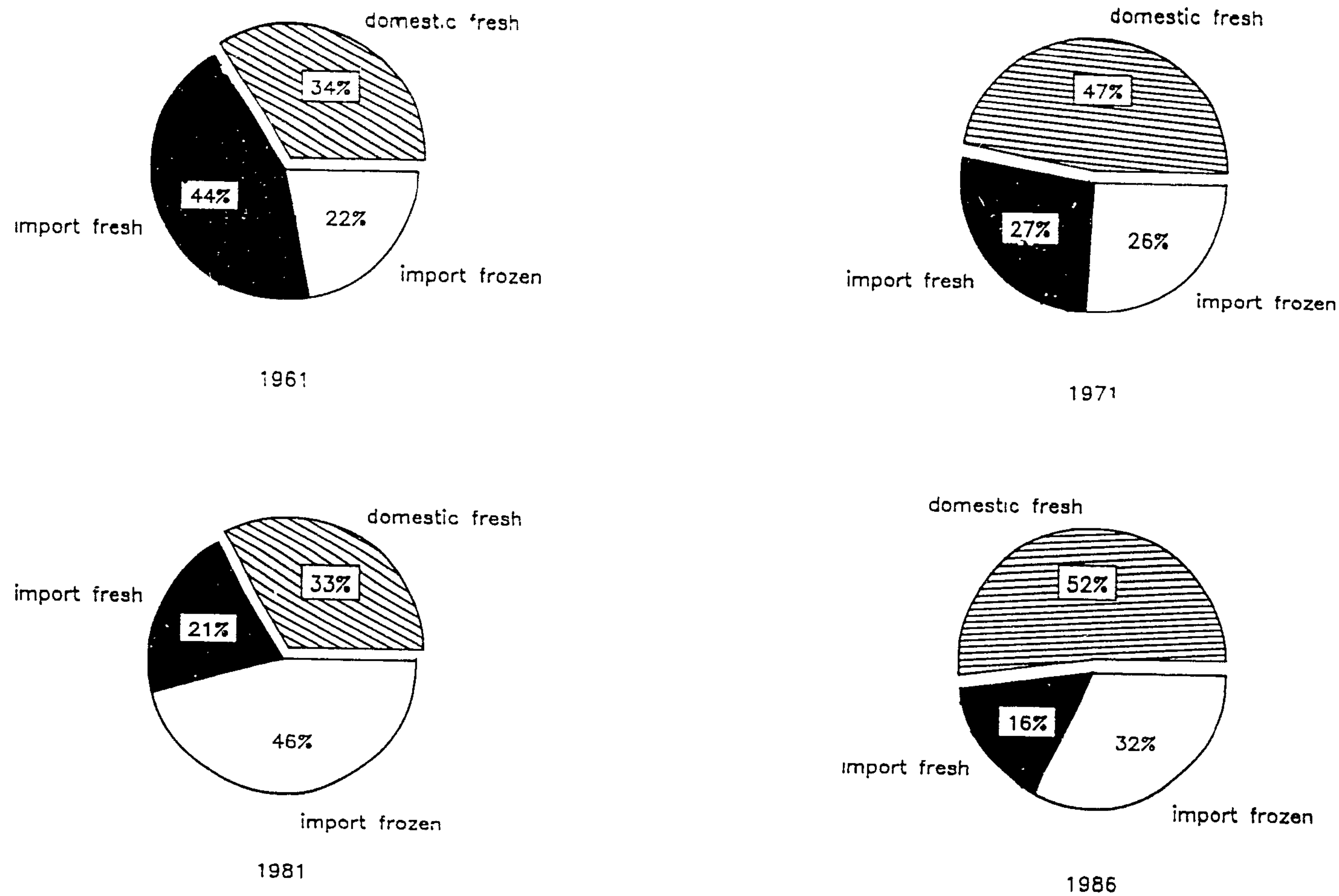

Figure 1. Strawberry supply in Québec (1961-1986).

Source Statistics Canada, 1986

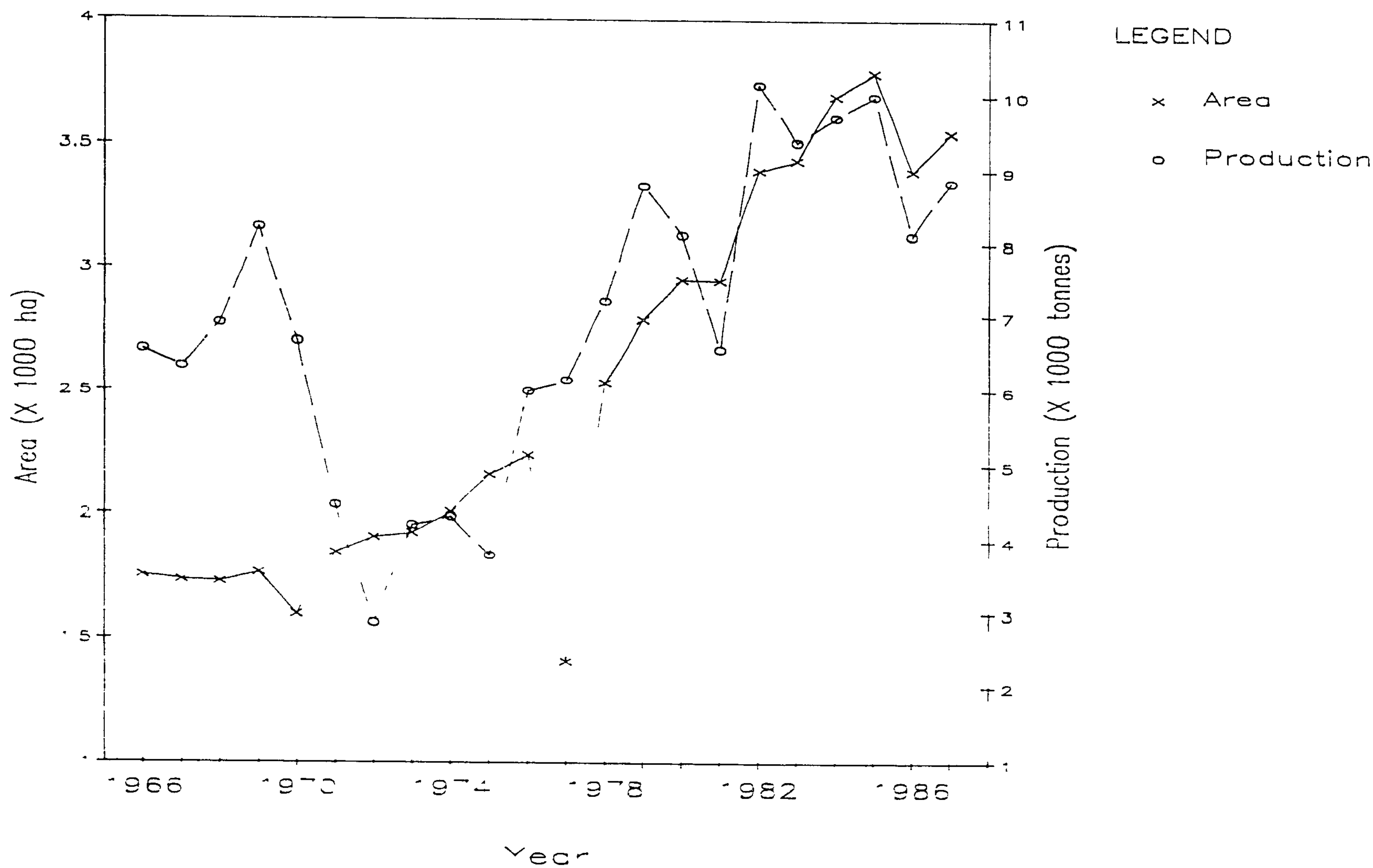

Figure 2. Evolution of strawberry production in Québec
(1966- 1986). Adapted from Berthelot, 1984 and Statistics Canada, 1986.

annual variations in strawberry supply make it difficult to establish a firm marketing strategy (CAGRIC, 1972).

On the national level, Canadian strawberry imports have maintained over 20,000 tonnes a year since 1984 (Figure 3). The United States, Mexico and New Zealand are our main suppliers. Some strawberries are now imported from Chile and Israel. Imported berries are mostly bought for processing.

Frozen strawberry per capita consumption data in Canada shows a 68% increase between 1971 and 1981 . This increase in the consumption of frozen berries was related to the decrease in the consumption of imported fresh and canned fruits. This corroborates the steady growth in the imports of berries for processing between 1971 and 1981. Canadian growers should be aware of this trend and grow increasing amounts of strawberries for processing.

Fresh domestic products could substitute imported ones in summer months (Figure 4). Canadian imports of fresh strawberries in June, July and August averaged 11 300 tonnes between 1984 to 1987. But to service this new market profitably with domestic berries, losses due to poor quality and spoilage will have to be reduced. For strawberries, Salunkhe and Desai (1984) evaluated losses to be 13.5% at the wholesale level, 5.5% at the retailer level and 22.2% at the consumer level for a total loss of 41.2%. In Québec, Lafleur (1985) estimated 15% of the berries delivered to the retailer were unmarketable while 44% were bruised. This reduced the gross profit from the sales of fresh strawberries by up to 93%.

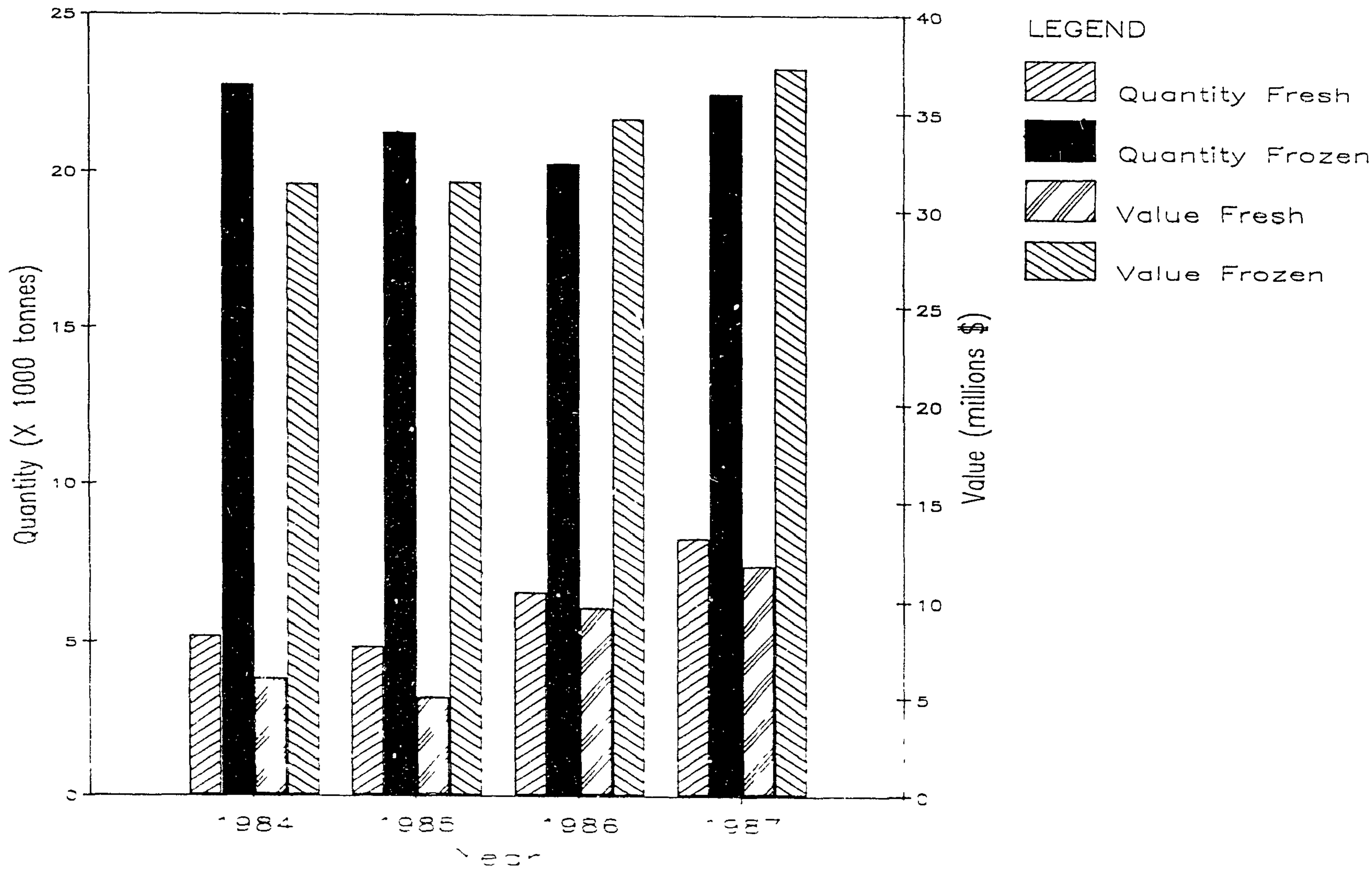

Figure 3. Canadian imports of fresh and frozen strawberries.
Source : Statistics Canada, 1987

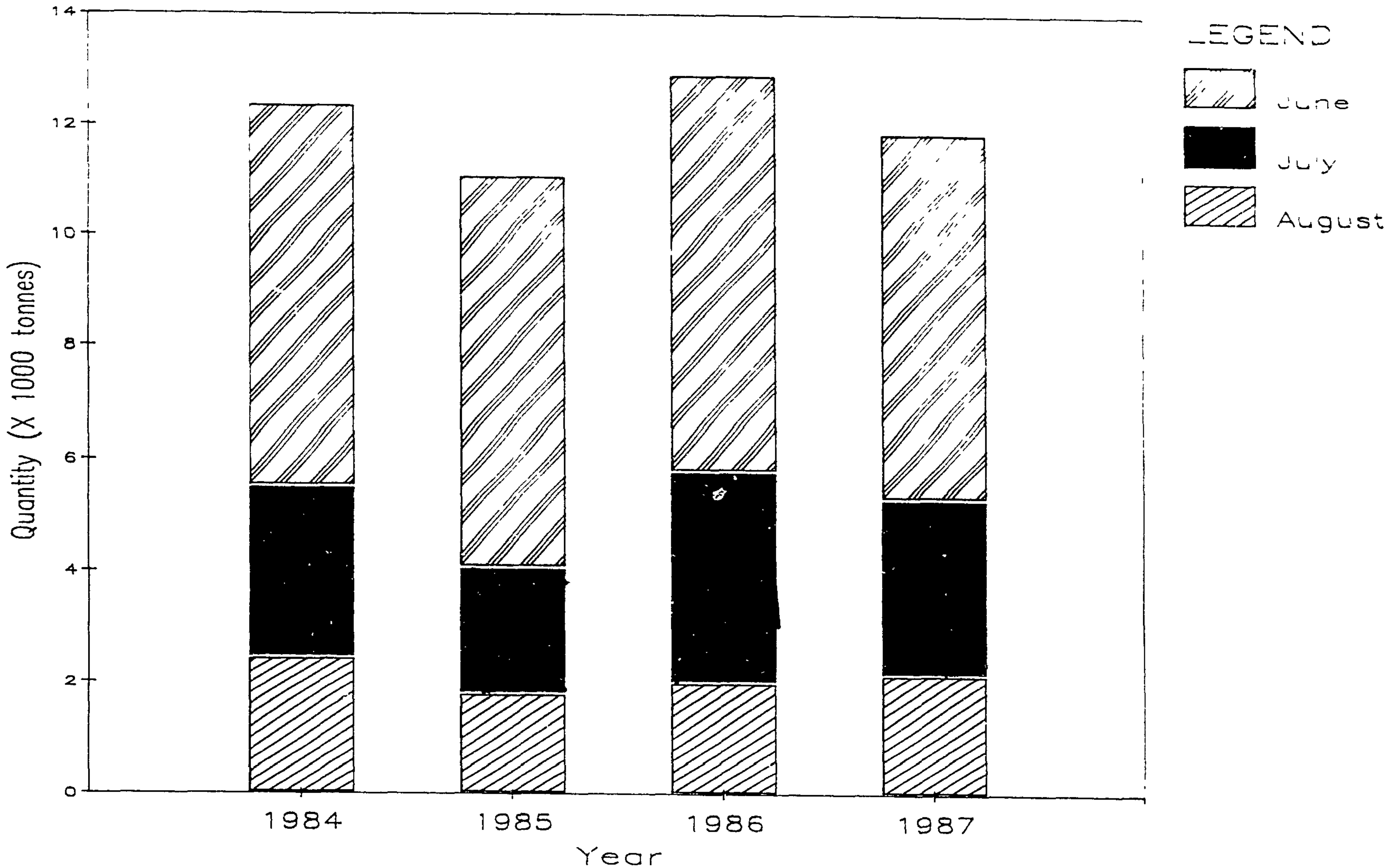

Figure 4. Typical fresh strawberry imports in Canada during summer months.

Source: Statistics Canada, 1987

Better management of harvesting, precooling and storage in controlled atmospheres (CA) are techniques that would reduce the losses significantly. There is no doubt Canadian growers could adapt some of these techniques to their operations. Adequate postharvest handling techniques would make it possible to ship strawberries across Canada and to increase our share of the market for fresh strawberries.

1.2. Methods of extending shelf life

Fungi present in the field at harvesting are responsible for later post harvest losses. Measures to control the level of infection in the field and after harvesting should be adopted for effective reduction of decay (Table 2).

Table 2. Methods of control of post harvest diseases

Control of post harvest diseases	
Pre harvest control	Post harvest control
- chemical control	- chemical control
- resistant cultivars	- refrigeration
- cultural practices	- precooling
- biological control	- CA storage
- harvesting	- irradiation

Planting sites should be selected with good soil drainage and air circulation to reduce humidity. Proper spacing of plants and application of fertilizers are important. Dense foliage produced by excessive use of nitrogen fertilizer or too narrow spacing will shade the berries. Shading will prevent fruits from drying during wet periods, creating ideal conditions for disease development. The use of mulch which keeps berries from contact with the soil is also helpful in limiting infections (Freeman and Pépin, 1977).

The control of post harvest diseases of strawberry must begin in the field where many of the infections are initiated. Fungicide treatments are the first action for controlling Botrytis and other fungi in the field. Breeding and planting plants that are resistant to pre and post harvest pathogens could be very effective in reducing losses; although the development of genetic resistance is a long process. Biological control of molds using saprophytic fungi is an alternative to fungicide treatments but much work still needs to be done before this technique is widely available (Bhatt and Vaughan, 1962, Tronsmo and Dennis, 1977).

Certain cultural practices can reduce the losses at harvest; berries should be picked early in the day as soon as it is dry, and handled carefully to avoid bruising. Prompt cooling to 0 to 10°C will check gray mold development and helps maintain the initial quality of the berries. Adequate storage at low temperatures and in CA extend shelf life significantly by retarding mold growth. The application of fumigants such as dichloran and sulfur dioxide can reduce the incidence of postharvest diseases but the effectiveness of these treatments is still debated (Smith and Worthington, 1965). Acetaldehyde, captan and dehydroacetic acid were also tested for postharvest applications but they affected the fruit quality (Jarvis, 1977, Cohen and Dennis, 1975). Radiation and heat treatments have been successful in controlling decay but no more better than the control achieved through conventional refrigeration of the berry. Maxie et al. (1971) and Wells (1970) have questioned the profitability of these methods.

There are many interacting factors involved in the control of postharvest diseases in strawberries. Measures to control the infestation and later development of pathogens are required at all levels if losses are to be reduced significantly. Plant scientists could help in selecting cultivars best adapted to post harvest storage; they could supervise spraying program and cultural practices and assess the degree of field infestation. Agricultural engineers could carry on work on the handling of the berries such as precooling, packaging, storage and distribution from harvesting to retailing.

1.3. Objectives

Strawberries are a fragile and short lived product. They are easily bruised when handled from the field to the distribution channels and they are very susceptible to decay. Harvested too ripe or stored under the wrong conditions, the product becomes even more perishable.

To find means to remedy these problems, a study on the post harvest handling of strawberries is proposed. The objectives of the present study are:

i) To assess the quality of strawberries after storage under CA and RA for 10 days followed by a two day storage under simulated commercial storage conditions

ii) To verify the suppressing action of CA on mold propagation from a decaying berry to the neighbouring strawberries.

The results of the study will help to find cost effective methods to improve the handling of strawberries.

1.4. Scope of the study

Control of postharvest diseases of strawberries is a multifaceted problem with many interacting factors. As mentioned, prevention of postharvest diseases begins in the field before or at harvest. In this study, the particular cultural practices used were not controlled. The fields, where strawberries were harvested , were maintained following practices commonly observed in Québec. Cultural practices such as mulching, fungicide applications, fertilization, irrigation and choice of the cultivar were not monitored before the experiment. Strawberries harvested were of the Red Coat variety, the most popular cultivar in Québec. Cultivars differ in their keeping quality and response to CA storage. This should be kept in mind when interpreting the results.

The level of infestation and the pathogens present in the field at harvest vary from place to place, from season to season and with time. Depending on weather conditions, the degree of success of improved management of harvesting and handling in controlling postharvest losses will vary.

At harvest and in subsequent steps of handling and storage, we followed the recommandations found in the literature that seemed most applicable to Québec conditions. Other workers might prefer different atmospheres for CA storage or would pick berries at a different maturity stage. In this case, recommandations given to harvest and handle other cultivars were satisfactory for our cultivar. Experience and further testing may lead to slightly different harvesting and handling procedures. It should be remembered the emphasis was on maintaining quality of berries for the fresh market. Processors may have a different opinion of what quality is and they may harvest berries much later to meet their processing requirements.

II - LITERATURE REVIEW

Fruits such as strawberries have a very short post harvest life even under optimum conditions. To maintain acceptable quality throughout the storage and distribution period, harvesting has to proceed before strawberries are fully ripe (Woodward and Topping, 1972). Adequate handling will maintain the quality of the berries until delivered to the consumers. The next section will describe various methods used to maintain the quality of the strawberries and to extend their shelf life.

2.1. Harvesting

As opposed to many other fruits that are picked green and ripened later, strawberries are fully ripe at harvest. When ripe, the flesh of the fruit is soft allowing it to be easily crushed and bruised. Later these injuries make the fruit more vulnerable to decay organisms and increase post harvest losses (El Goorani and Sommer, 1981). Common problems encountered while picking strawberries for the fresh market are harvesting fruits that are too ripe, picker damage, rough field handling and delayed cooling (Mitchell et al., 1964).

2.1.1 Harvesting for the fresh market

Depending on the time and distance to market, strawberries are harvested at different stages of ripeness. Fruits for local market should be fully ripe and firm while fruits for long distance shipment or to be stored should be picked at the three fourths colored stage or white tip stage (Woodward, 1972). Picker training and supervision can significantly reduce the market losses. Mitchell et al. (1964) observed selection of berries by careful pickers resulted in 14.4% unmarketable fruits after 8 days at 5 °C while careless pickers caused 33.7% of the berries to be unsalable.

Careful pickers snapped the fruit from the plant without bruising the berry or breaking the cap. Careless or inexperienced pickers squeezed the fruits and dropped them in the crates. They also filled the crates to the point where berries were crushed when crates were stacked. In Québec, commercial strawberry harvesting is done mostly by untrained pickers and substantial losses can be attributed to their inexperience (Girard, 1985). Most growers make a real effort to avoid rough handling of their fruits during stacking and loading. However they overlook good temperature management, probably because the end results are not so immediately apparent. Ideally, harvested fruits should be shaded in the field and moved as quickly as possible from picking to cooling stations.

2.1.2 Harvesting strawberries for processing

An increasing percentage of strawberries sold to processors are harvested mechanically. In fact in many areas, mechanical harvesters are now a necessity because of labor scarcity and expenses. A cost comparison between hand and machine harvesting is presented in Appendix A. Major changes in cultural practices are required to adapt the crop to mechanical harvesting. First, firm fruited, dark fleshed, uniform ripening cultivars must be found and planted. Secondly, shaped beds are recommended to improve the machine picking efficiency (Morris, 1980). Over the years, several harvesting principles have been tried. Cutting or clipping the fruits from the plants was rejected because most of the large fruits were not harvested (Morris, 1983). A comb brush stripping mechanism is now used successfully on many harvesters (Figure 5). A stream of air lifts the fruit above and in front of the comb brush stripping mechanism. Moving on a continuous belt, the comb brush strips the fruits from the plants and conveys them to an air lock valve. From this valve, fruits are picked and packed in containers (Morris, 1980). When used with shaped beds, such harvesters operate at a 95% harvesting efficiency. The harvesting proceeds once the majority of the crop has developed an acceptable color. Although the product contains a wide range of maturities, samples containing up to 50% immature fruits can be used in the production of an acceptable jam (Spayd and Morris, 1981). Picking early ripening fruits by

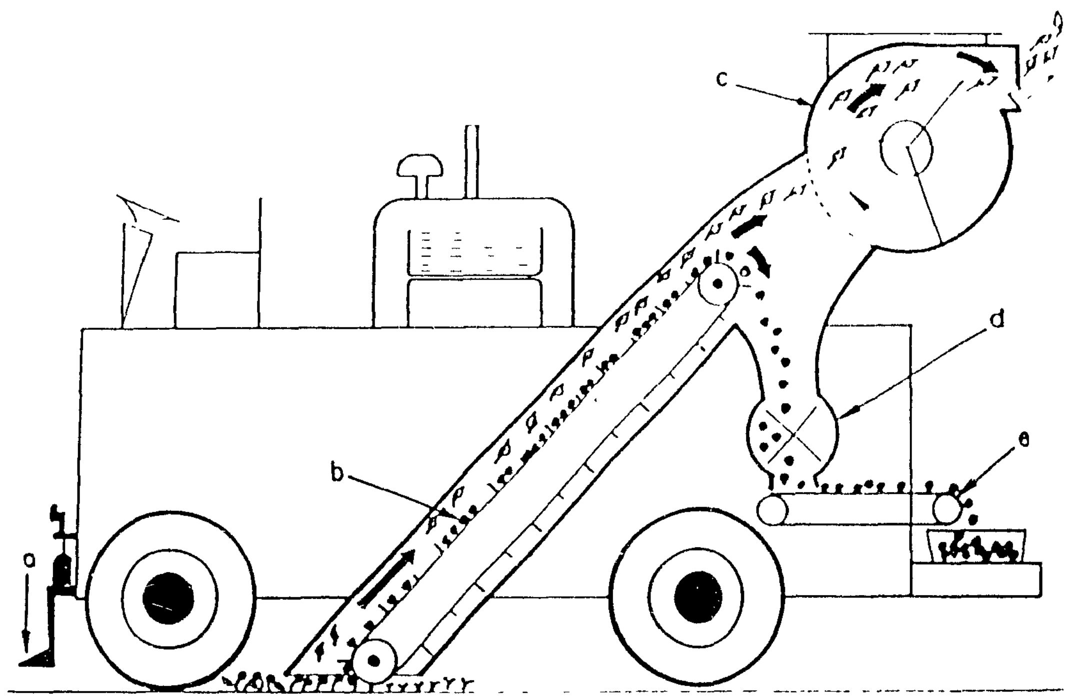

Figure 5. Schematic of a mechanical strawberry harvester showing a) the moving sickle bar b) the comb brush picking and conveying system c) the fan blowing leaves away d) the air lock valve and e) the fruit transporting conveyor.

hand improves the quality of the machine harvested fruits. For some cultivars, it also increases the total yield harvested (Morris, 1980).

Before being delivered to the processors, machine harvested strawberries are usually cleaned from leaves and debris using a dump wash tanks, trash eliminators and decappers. A grading unit is used next to sort the berry by maturity based on fruit size (Dale, 1985, Morris, 1980).

2.2. Precooling

To market strawberries profitably on a regional scale, they must keep for at least a few days. Storage at low temperatures is the simplest and most efficient way to maintain strawberry quality (El Goorani and Sommer, 1981). Storage at low temperatures reduces the activity of pathogens such as Rhizopus and Botrytis species which are unable to produce sporangia at temperatures below 10°C. Their growth and ability to establish new infections are also greatly reduced in the 0°C to 10°C temperature range (Khalid and Jordan, 1976). Maximum growth and sporulation by Rhizopus occur between 15 to 30°C; infected fruits stored at 20°C will be totally spoiled within 48 hours. At 10°C, rot lesions may be evident less than 24 hours after inoculation.

Most products are cooled in the same room they are stored in with no special facilities for the cooling operation. This method involves less handling and simpler design and operation for the cold room (Guillou, 1960). Cooling to the desired temperature is slow and takes place over a period of many hours. Highly perishable products such as strawberries, may deteriorate during the time they are cooled. while warm products are added to the cold room, stored products are exposed to continual variations in temperature and humidity. In turn, this causes condensation of moisture on the colder product, making it more susceptible to fungal infection (Hart, 1964, Tonini, 1983). Finally in a slow cooling operation, additional refrigeration is necessary to extract the heat of respiration which may be significant for products having a high rate of respiration. In room cooling, the cooling rate of berries can be accelerated by substituting plastic mesh master trays for the regular fiberboard trays. Harris et al. (1969) reported the cooling rate to be twice as fast with the plastic mesh tray. They also reported room cooling of berries to be 20% faster when berries were in plastic baskets rather than in pulp baskets. In forced air precoolers, the type of baskets had little influence on the cooling rate.

The importance of rapid precooling cannot be overemphasized since twice as much decay occurs in berries held at 12.8^{o}C as at 1.1^{o}C and four times as much decay occurs at 21.1^{o}C as at 4.4^{o}C. A delay of 10 hours in cooling strawberries from 20^{o}C to 4.4^{o}C caused a 20% increase in Botrytis cinerea infections in berries stored for three days at 4.4^{o}C (Tonini, 1983). A 20 hour delay in precooling caused a 40% increase in B. cinerea infections.

Cooling can be accelerated by increasing the area exposed to cold air and by creating air movement in the cold room. To further accelerate cooling, cold air must be driven into or through the containers. Precoolers were developed for this purpose. By circulating a cold fluid around the product to cool, the heat transfer is greatly increased resulting in shorter cooling time. Different types of precoolers are available.

Vacuum coolers are well adapted to cool leafy vegetables. In these coolers, air is pumped away in the storage room until moisture evaporates rapidly from the product. Fast cooling occurs as the heat available in the product is used to evaporate the water. The resulting water vapor is then condensed by refrigeration and run into a sump. The half cooling time for strawberry in a vacuum cooler is about 25 minutes; for lettuce, it is 3 minutes (Guillou, 1960). Strawberries are cooled quicker and cheaper by hydrocooling or forced air cooling. Vacuum cooling equipment is expensive and requires skilled labor. Large daily outputs are necessary for economical operation.

Strawberries can be precooled by circulating cold water around them (hydrocooling) but, unless they are handled in bulk, water resistant containers would be required. Draining off excess water would also be required. Any rise in temperature when packing hydrocooled product must be offset by additional refrigeration. With hydrocooling, damage to the product from wetting or from infections carried by the water is also a possibility. Cold air has none of the drawbacks of hydrocooling and for berries it is equally effective (Guillou, 1960). Forced air cooling is brought about by use of a difference in air pressure to force air through stacked containers. Forced air cooling is best adapted to situations where the pack is open. That is why forced air precooling is the most common method used to precool small fruits. Air circulation is provided by large fans that draw air through containers positioned to favor air circulation around the berries (Harvey et al., 1969). Less than 1% of the producers precool their fruits in Québec (Girard, 1985). The small size of the operation, direct and local marketing explain to some extent why this is so. Yet 150 producers cultivating areas larger than 2 hectares would benefit from precooling and cold storage (Girard, 1985).

In Québec, most growers harvest less than 0.5 tonnes of strawberries per day. This small production and the short season cannot justify the installation of an elaborate precooler. A modular precooler, simple in design and inexpensive to build would likely meet the needs of most growers if it was available on the market.

2.3. Storage of Strawberries

Fruits and vegetables are still alive after harvest and their development continues. But because the harvested fruit is cut from its normal source of water and has only a limited supply of carbohydrate to respire, premature senescence, rotting and wilting are promoted unless fruits are maintained in a controlled environment.

Many storage systems are available to store fruits and vegetables. During storage, stored products can lose significant amount of moisture to the cold dry air. For strawberries however, moisture losses during storage are rarely a problem because the storage period is short and the epidermis of the berry is fairly impervious (Woodward, 1972). In areas where moisture losses could become a problem, the use of high humidity storage systems such as the jacketed system or the Filacell system could be recommended. Both systems would have to be downscaled to meet the growers need. If desired, the Filacell system could be adapted to CA storage systems (Krahn and Darby, 1971). Storage at reduced atmospheric pressure has been tested in Florida and Michigan and in one instance, the storage life of strawberries was extended to 21 days under hypobaric storage compared to 5-7 days in conventional cold room (Burg, 1975). Yet the economic feasibility of commercial hybobaric storage for strawberries is still uncertain in the U.S.A. and is likely not to be profitable under the short Canadian operating season (Lange et al., 1978).

CA storage of strawberries is mostly developed in the United States for long distance transportation. In this storage system, gases involved in the metabolism of the stored commodity are added or removed. In general, O_2 is reduced and CO_2 is increased. Other gases such as ethylene (C_2H_4) and carbon monoxide (CO) are also controlled when necessary. Storage in CA greatly improves the storability of strawberries because it reduces their metabolic rate and delays their ripening (El Goorani and Sommer, 1981). Reduction in the respiration rates are attributed to low oxygen concentrations and in general, are most noticeable when O_2 concentrations are lowered below 8 to 10%. If the O_2 level becomes too low in the storage room, fermentation occurs and off flavors develop (Couey and Wells, 1970). The critical O_2 concentration below which fermentation takes place is different for each species and variety of plants and varies with the temperature and the length of exposure. For strawberries stored at 4°C, the critical concentration is at 2 % O_2 and 98% N_2 (Woodward and Topping, 1972, Couey et al., 1966).

The role of CO_2 in CA storage is to decrease or inhibit the growth of pathogens, to decrease the rate of oxidation of plant compounds and to reduce the losses in acidity, firmness and chlorophyll (El Goorani, 1981). Certain fruits and vegetables such as peaches and tomatoes, are susceptible to CO_2 and exposure to high concentrations of CO_2 results in off flavors, soft tissue and internal and external browning of the tissue. Strawberries are not susceptible to CO_2 injury although during prolonged exposure to concentrations greater than 30%, off flavors developed (Harris and Harvey, 1973). Compared to other fruits, strawberries store best at high CO_2 levels.

2.3.1. Controlled atmosphere storage of strawberries

Controlled atmospheres can be created and maintained using three different types of systems which are: the O_2 control systems, the CO_2 control systems and the membrane system. In the O_2 control systems, the O_2 is depleted by burning it in catalytic burners, purging it by pulverising liquid nitrogen in the storage room or by pumping the air out of the room (hypobaric storage). In the CO_2 control systems, CO_2 is first rised by pulverising liquid CO_2 in the room or by making the storage room airtight and letting the CO_2 produced by the respiration of the stored products to accumulate in the atmosphere. Once the desired CO_2 level is reached, it is maintained by circulating the gas flow through a scrubber which removes any excess. Water, hydrated lime, activated charcoal and molecular sieve are the main reagents used commercially for CO_2 absorption. The O_2 concentration is usually maintained by letting air into the storage room. The O_2 and CO_2 control systems are not adapted to short term storage of strawberries unless a source of CO_2 is available. The use of membrane systems, where a semi permeable membrane regulates the gas exchange between the inside and the outside of the cold room, would also be limited for strawberries because of the time required to create the CA. Secondly, the gas exchange characteristics of the membrane available do not lead to CA with both high CO_2 and O_2 concentrations. Raghavan and Gariepy (1984) have used a membrane system successfully to store a number of vegetables and work is underway to design a membrane system which would allow O_2 and CO_2 levels in the range of interest for strawberry storage.

2.3.2. Gas composition for controlled atmosphere storage of strawberries.

A summary of the different studies reviewed on the CA storage is presented in Table 3. In the early experiments conducted between 1900 and 1950, the storage temperatures were often higher than optimal because CA was tried as a possible alternative to low storage temperatures (Brooks et al., 1932, Doren et al., 1941). Brooks et al. (1932) found that an atmosphere composed of 18% CO_2, 17% O_2 and 65% N_2 had a checking effect on decay of strawberries stored under CA. As a result, better management of temperature was introduced (Guillou, 1960, Harvey et al., 1965). Precooling and lower storage temperatures became standard in California shipments. The airtightness of the containers was also improved to provide for more steady CA composition (Harvey et al., 1980). As a result of these improvements, storage of strawberries was extended from one day in 1965 to 3 to 5 days in 1973 and 4 to 7 days in 1980 and recommended storage temperatures dropped from 10°C to 4 to 7°C (Harvey et al., 1980).

The gas compositions used in CA storage were also improved to reduce decay to a minimum while preventing the development of off flavors or CO_2 injury. Lower CO_2 concentrations did not reduce fungal growth significantly enough to extend shelf life while higher

Table 3. Effect of different storage conditions on strawberry decay and quality.

Gas concentrations %O_2	%CO_2	%N_2	Temp. °C	Length days[1]	Decay %[2]	Off[3] flavors	Marketing days[4]	Temp.[5] oC	Decay[6] %	Reference
18	2	80	2	10	---	N	---	---	---	Fulton, 1907
13	8	79	2	10	---	Y	---	---	---	" "
---	36	64	2	10	---	Y	---	---	---	" "
17	18	65	10-16	2	N	N	---	---	---	Brooks et al., 1932
17	23	60	10-16	2	N	Y	---	---	---	" " "
18-19	10-13	69-71	10-16	2	N	Y	---	---	---	" " "
17	15	68	10	4	N	N	2	21	100	Doren et al., 1941
15-->21	30-->0	55-->79	10	4	N	Y	2	21	100	" " "
6	15	79	0	7	---	Y	---	---	---	Smith, 1938
11	10	79	0	7	---	N	---	---	---	" "
13	27	60	8-10	1	8	N	2	15	24	Harvey et al., 1965
21	---	79	8-10	1	10	N	2	15	33	" " "
0.25	0	99.75	3	5	---	Y	2	15	1.4	Couey et al., 1966
0.50	0	99.50	3	5	---	N	2	15	3.8	" " "
21	--	79	3	5	---	N	2	15	10.0	" " "
16-19	10-20	64-71	3	1.5	---	N	1	15	7.5	Couey and Wells, 1970
15	30	55	3	1.5	---	Y	1	15	5.5	" " "
21	---	79	3	1.5	---	N	1	15	16.7	" " "
19	10	71	10	3-5	1.3	N	2	15	8	Harris and Harvey,1973
16	20	64	10	3 5	1.7	N	2	15	11	" " "
15	30	55	10	3-5	4.5	Y	2	15	26	" " "
21	---	79	10	3-5	11.4	N	2	15	64	" " "
16-19	10-20	64-71	4-7	3	---	N	2	16	5	Harvey et al., 1980
21	---	79	4-7	3	---	N	2	16	33	" " "
16	20	64	6	8	0.1	N	1	15-19	7.2	Lange et al., 1978
1.0	---	99	6	8	13.9	N	1	15-19	42.9	" " "
2.3	5.0	92.7	3.3	21	14.0	N	---	---	---	El Kazzaz et al., 1983
17.5	15.0	67.5	3.3	21	0.2	N	---	---	---	" " "
21.0	---	79.0	3.3	21	19.3	N	---	---	---	" " "

Note: N: no Y: yes; 10-15°C means 10 to 15°C; 10-->15°C:means at t=0,temperature is at 10°C and rises to 15 °C at end of storage.

1- Length of storage in days.
2- % decay in strawberries at end of storage.
3- Off flavors detected or not.
4- Length of storage in days where berries were left at a given temperature after storage in CA.
5- Temperature at which berries were left during the marketing period.
6- % decay in strawberries at the end of marketing period.

CO_2 concentrations lead to the development of persistent off flavors (Brooks et al., 1932, Harris et al., 1969, Couey and Wells, 1970). The best gas mixtures were those where 15 to 20% CO_2 was present with nearly equal amounts of O_2. Adding CO_2 in air using dry ice or liquid gas was the method used commercially to get the desired gas concentrations (Brooks et al., 1932, Harris and Harvey, 1973).

Couey et al. (1966) used liquid nitrogen to lower O_2 concentrations to store strawberries at 3 °C for 5 days in atmospheres composed of 0 to 1% O_2 and 99 to 100% N_2 . Oxygen concentrations below 0.5% decreased decay caused by B. cinerea to 4% while decay affected 10% of the berries stored in air. Off flavors developed in fruits held in O_2 concentrations of 0.25% or less. In later studies, Couey and Wells (1970) studied the possible commercial use of storage in low O_2 atmospheres. Storage in atmospheres containing low O_2 concentrations (below 1%) was not recommended as it is very sensitive (Couey and Wells, 1970). The authors recommended atmospheres composed of 10 to 20% CO_2, 16 to 19% O_2 and 64 to 71% N_2 as an effective means of reducing decay in stored strawberries without causing off flavors. Lange et al. (1978) kept strawberries for 8 days at 6°C in an atmosphere composed of 20% CO_2, 16% O_2 and 64 % N_2. At the end of storage, only 0.1% of the berries stored in CA were decayed compared to 13.9% decay in berries stored in air. Moreover, after an additional day of storage in air at temperatures between 15 and 19 °C, only 7 % of the strawberries previously stored in CA were decayed compared to 42.9% decay in berries previously stored in RA. El Kazzaz et al. (1983) stored strawberries for 21 days at a temperature of 3.3°C in an atmosphere composed of 17.5% O_2, 15% CO_2 and 67.5% N_2. At the end of the storage period, only 0.15% of the strawberries stored in CA were decayed while decay affected 19.3% of the berries stored in RA. Results of these studies are examples of the effectiveness of CA in the ranges recommended to maintain strawberry quality.

2.4. Use of Controlled Atmosphere in Combination with Other Treatments

Successful transport and short term storage of strawberries are dependent on the extent to which decay organisms can be controlled. Various treatments such as preharvest applications of fungicides, irradiation and addition of gases such as carbon monoxide (CO) to the CA can improve the effectiveness of CA in controlling fungal growth.

2.4.1. Irradiation

Chalutz et al. (1965) compared the effectiveness of CA in inhibiting the growth of B. cinerea on irradiated and unirradiated strawberries packed in airtight microbes proof packages. When stored in an atmosphere composed of 10.5% CO_2, 4.8% O_2 and 84.7% N_2, 83.3% of the strawberries irradiated with a dose of 200 Krad were still marketable after a storage period of 16 days at 5 °C. When stored in air, only 40.5% of the irradiated berries were marketable at the end of storage.

Chalutz et al. (1965) noted there was little benefits derived from combining CA with irradiation to inhibit Botrytis cinerea growth . Later studies under actual transit conditions showed disease control with irradiation was only as good as conventional refrigeration (Maxie et al., 1971).

2.4.2. Fungicides

Depending on seasonal weather conditions, fungicide applications may help reduce postharvest losses by reducing field infection by pathogens (Borecka and Millikan, 1981). In a storage experiment, berries harvested from plants sprayed with 0.1% Benlate 50WP (Benomyl) at tight cluster, full bloom and fruit set, and stored in an atmosphere composed of 20% CO_2, 3% O_2 and 77% N_2, kept better than berries from unsprayed plants. Decay affected 45% of the berries from sprayed plants compared to 60% of the berries from unsprayed plants. In a later experiment, no rot developed in berries picked from plants sprayed with Benlate or Bavistin (carbendazim) and stored in CA for 20 days at 4^{o}C. Different results were recorded in the second experiment because the weather during bloom through ripening was warm and dry and was unfavorable to infection. During the first year, the weather conditions in late Spring and early summer were cool and wet, and favored infection of strawberries by <u>B. cinerea</u>. Because field infection was more limited the second year than the first year, fungicide applications and CA storage were more effective in controlling pathogens.

2.4.3 Effect of ethylene and carbon monoxide

While strawberries are stored in CA, gas such as ethylene is produced by the berries and its accumulation in the atmosphere may affect their keeping quality. El Kazzaz et al. (1983) observed that the presence of 20 ppm of ethylene in an atmosphere composed of 5% CO_2, 2.3% O_2 and 92.7% N_2 promoted fungal growth. After 21 days at 0.6 ^oC, 14.0% of the berries stored in CA were decayed while 17.6% were rotted when 20 ppm ethylene was added to the CA. Strawberries stored in atmospheres containing 20 ppm ethylene were also softer than fruits stored in air or CA but there was no difference among treatments with respect to off flavor, sweetness, soluble solids content and titratable acidity. El Kazzaz et al. (1983) suggested that the scrubbing of ethylene from the atmosphere of storage rooms might be advantageous because of its effect on disease development and its effect on fruit firmness.

Carbon monoxide (CO) can be added to CA to improve its fungistatic effects (El Goorani and Sommer, 1979). In atmospheres composed of 2.3% O_2, 5.0% CO_2 and 92.7% N_2, cultures of B. cinerea on strawberries stored at 5.5 ^oC for 19 days spread over the fruits at a rate of 1.2 mm per day. When 9.0% CO was present in the CA (2.3% O_2, 5.0% CO_2 and 92.7% N_2), the growth rate of the fungi was reduced to 0.3 mm per day. Later, El Kazzaz et al. (1983) observed only 0.15% of the berries stored in 10% CO, 2.3% O_2, 5.0% CO_2 and 82.7% N_2 for 21 days at 0.6^oC were decayed while 14.0% of the berries stored in CA (2.3% O_2, 5.0% CO_2 and 92.7% N_2) were decayed.

Use of CO in the making of CA could thus help suppress fungal growth but the use of CO in storage have serious limitations because of its toxicity to humans and the danger of explosion at concentrations between 12% and 75% (v/v).

2.5. Effect of Storage Conditions on Strawberry Physiology and Quality

The maturity of strawberry at harvest influences their shelf life and quality. In general, immature berries store well compared with mature ones. From petal fall, a strawberry requires about 40 days to develop fully. The growth rate throughout this period is fairly steady and slows only in the last days of development (Woodward, 1972). After about 42 days, growth ceases and the fruit enter a period of rapid ripening which lasts two to five days. Quality factors such as titratable acidity, soluble solids (SS), soluble sugars, pH and color are used to evaluate the ripeness of fresh strawberries.

2.5.1. Chemical composition of strawberries

Soluble solids, soluble sugars and titratable acidity increase steadily during the development and ripening periods. At senescence, titratable acidity in overripe fruits tends to decrease while soluble sugars maintain or increase (Figure 6) (Woodward, 1972). After about 42 days, growth ceases and the fruit enter a period of rapid ripening which lasts two to five days. Quality factors such as titratable acidity, soluble solids (SS) soluble sugars, pH and color are used to evaluate the ripeness of fresh strawberries.

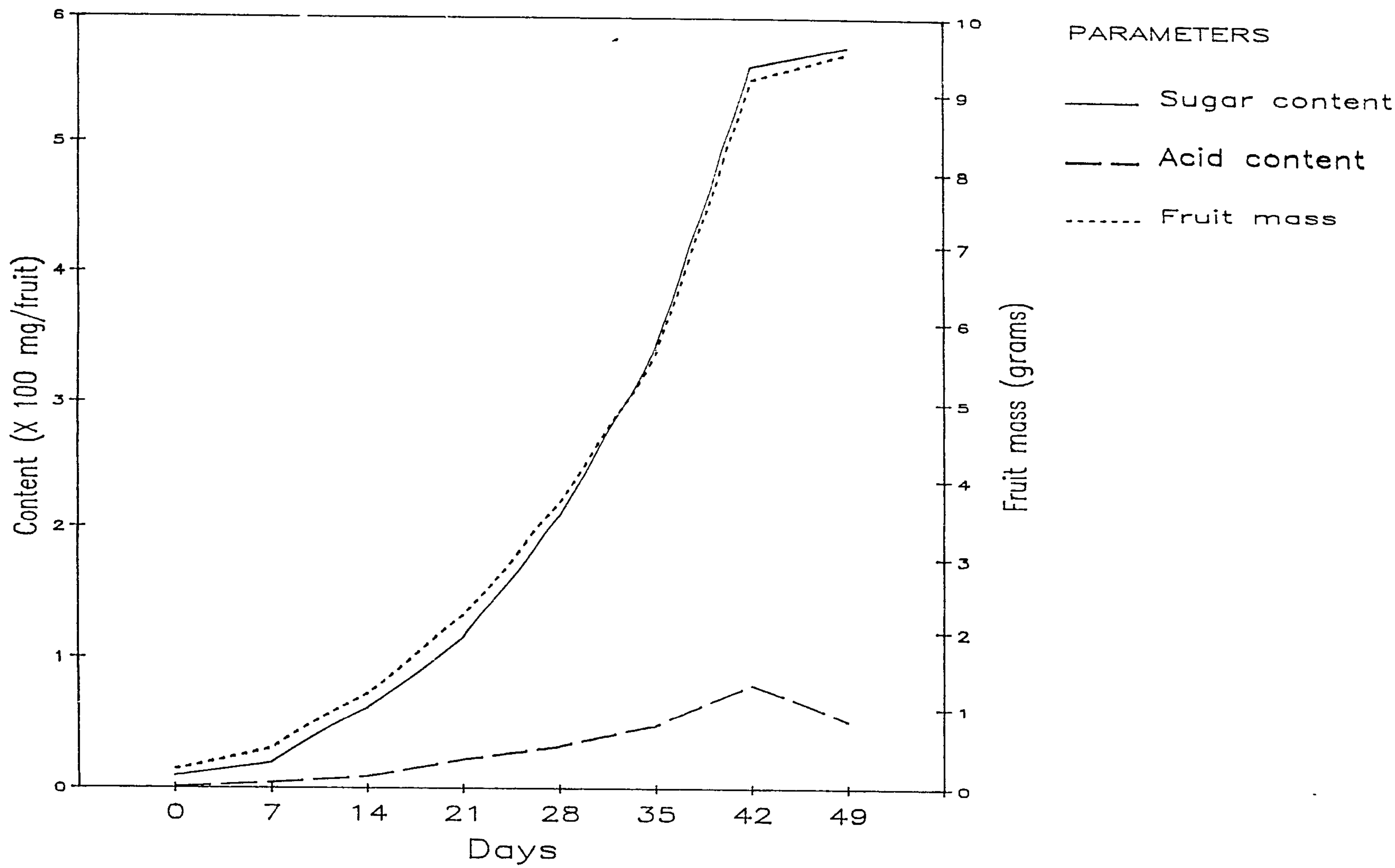

Figure 6. Physical and chemical changes in developing strawberry. (Adapted from Woodward, 1972).

At maturity, the total sugar content of strawberry ranges between 2.81 to 8.81 per cent of the fresh weight depending on the cultivar (Money and Christian, 1950). The average sugar content of mature berries is about 5.0% with 0.87% as sucrose and 4.13% as reducing sugars. Sweeney et al. (1970) report strawberries grown the first year are higher in soluble solids and sugars than those grown the second year. In taste panel scores, they found flavor was usually significantly related with sugars, SS and with the SS to titratable acid ratio. A sugar to acid ratio of 5.3 and a SS to acid ratio of about 9 were found typical of mature berries (Sweeney et al., 1970). Glucose and fructose are the principal sugars found in strawberries.

At maturity, citric and malic acids are the main organic acids found in strawberries. Trace amounts of quinic succinic, glyceric, glucollic and oxaloacetic acids can also be found (Sweeney et al., 1970). The titratable acidity of a typical ripe fruit is 1.01% (w/w) with 0.92% as citric acid and 0.09% as malic acid. Depending on the cultivar, the titratable acidity at maturity varies from 0.57 to 2.26% and the pH from 3.3 to 3.7 (Woodward, 1972, Skrede, 1980).

In the development of strawberries, color changes are associated with changes in the concentrations of pigments. Until about 30 days after petal fall, the developing strawberry is green and little color change occurs. Past this time, the synthesis of carotenoid (yellow pigments) and chlorophyll (green pigments) stop while the production of anthocyanin pigments (red pigments) picks up to increase rapidly on the 35 th day (Woodward, 1972). The average anthocyanin content of a mature strawberry lies between 40 to 80 ug/gram fresh weight. Light and temperature influence the production of anthocyanins and in the field, full color development occurs in one or two days depending on the weather. In storage, strawberries harvested at the white stage will develop full color at room temperature notwithstanding the temperature and light level. However, in white strawberries stored in the dark and at 10°C, normal color development is impaired. Ascorbic acid or vitamin C is the vitamin found in greatest concentrations in strawberries. A typical average concentration of vitamin C in strawberry is 60 mg/100 gram fresh weight (Oliver, 1967). The ascorbic acid content of strawberries is low until the onset of color development (30 to 35 days after petal fall). Vitamin C content increases in ripening berries but decreases in overripe ones.

2.5.2. Effect of CA on chemical composition of strawberries

Unusual concentrations of O_2 and CO_2 in the atmosphere around stored fruits affect their physiology and delay senescence. The effects of CA on the parameters measured to find the degree of ripeness show how a given CA can control physiological breakdown of the stored fruit.

El Kazzaz et al. (1983) did not find any difference in the SS content and titratable acidity of strawberries stored for 21 days at

3.3°C in air or in atmospheres composed of 17.5% CO_2 and 67.5% N_2; 2.3% O_2, 5% CO_2 and 92.7 % N_2. Borecka and Millikan (1981) found increased acidity and reduced SS in strawberries stored for 10 days at 4°C in air compared to berries stored in atmospheres composed of 3% O_2, 20% CO_2 and 77% N_2. Soluble solids content in berries stored in CA was 9.50% compared to 8.18% in the control and titratable acidity in strawberries stored in CA was 0.65% compared to 0.74% in berries stored in air. When the experiment was repeated, no significant difference was found in the SS and the acidity of berries stored in CA or in air. In a third experiment where the storage period was extended to 20 days, strawberries stored in air had a higher acidity than berries stored in CA although no significant difference was found in the SS content of strawberries stored in air or in CA. The authors concluded there was no consistent difference in SS or in acidity that could be associated with the type of storage used.

Plocharski et al. (1978) stored strawberries for 12 days at 6 °C in air and in atmospheres composed of 1% O_2 and 99% N_2; and 16% O_2, 20% CO_2 and 64% N_2. During storage, he monitored the changes in acidity, anthocyanins, hydrogen ion activity and vitamin C. For all treatments, there was no change in total solids during storage. Gradual losses in acidity and hydrogen ion activity were observed for all treatments. Yet fruits stored under low O_2 concentrations had the smallest changes in acidity with 18% decrease while the acidity of strawberries stored in air decreased by 25% and by 32% in berries stored in 20% CO_2. Hydrogen ion activity decreased by 40%

in berries stored in air or under high CO_2 atmospheres, but only 22% under low O_2 atmospheres. Plocharski et al. (1978) explained that in the low O_2 atmospheres, the acids were better preserved because respiration was suppressed. The changes in SS and in anthocyanin content during storage were very small and differences between treatments were not significant. Plocharski et al.(1978) concluded that because of the stability of the anthocyanins during cold storage, the fruits for immediate consumption after storage should be harvested when they are properly colored. The rate of degradation of vitamin C under atmospheres containing 20% CO_2 was greater than in the other treatments. In strawberries stored in 20% CO_2, 26% of the vitamin C was lost compared to 9% in berries stored in 1% O_2 and 18% in berries stored in air. The low O_2 atmosphere helped in the preservation of vitamin C by limiting its oxidation.

2.5.3. Effect of storage conditions on respiration

Overholser et al. (1931) studied the respiration rate of immature and mature strawberries in modified atmospheres at 20°C. In their experiment, CO_2 levels were increasing while O_2 levels were decreasing by about the same percentage CO_2 was produced. With concentrations in the range of 7 to 12% CO_2, they found no depressing effect during 16 to 18 hours monitoring periods. During the longer period and with a higher CO_2 content, respiration intensities were slightly greater. Respiration rates in air averaged 81 mg CO_2/kg hr and 93 mg CO_2/kg hr for mature fruits.

The respiration quotient (ratio of CO_2 produced to O_2 consumed) was less than one indicating there was probably no anaerobic respiration. Therefore, at these CO_2 levels, all CO_2 released likely came from the complete oxidation of hexose sugars.

Haller et al. (1933) found respiration rates at 20°C close to the ones of Overholser et al. (1931). They studied the respiration rate and respiration quotient of strawberries in relation to temperature. At lower temperatures, they observed that the temperature coefficient was greater than at higher temperatures. The temperature coefficient is the number of times the respiration rate is increased by a 10°C rise in temperature. For instance, the temperature rise from 0 to 10 °C more than tripled the respiration rate while a temperature rise from 11 to 21 °C doubled it (temperature coefficients of 3.65 and 2.05 respectively).

Haller et al. (1933) obtained different respiration quotients than Overholser et al. (1931) . While Overholser et al. (1931) had a quotient close to unity for the variety they studied, Haller et al. (1933) found a quotient of about 1.3 at most of the temperature studied. This higher respiration quotient indicated, CO_2 released likely came from the oxidation of citric acid. This observation might be of interest in respiration studies where respiration rate is evaluated from the measurements of heat production by the berries because the complete oxidation of citric acid gives off only 70% as much heat as the oxidation of dextrose.

Thornton (1933) studied the O_2 uptake by strawberries at 25°C in concentrations of carbon dioxide varying from 0 to 76%. His experiments lasted from 4 to 41 hours and sample weights varied from 106 and 439 grams. Oxygen uptake by strawberries was not retarded by carbon dioxide until a concentration of more than 50% CO_2 was used.

Woodward and Topping (1972) studied the effect of low O_2 atmospheres on the O_2 uptake of strawberries. Berries were stored in air or in atmospheres containing 1.2% O_2 and 98.8% N_2 or 5% O_2 and 95% N_2 at 4.5°C for 12 days.

The O_2 consumption was lower in fruits stored under lower O_2 concentrations and varied during the experiment. In all treatments, there was an initial decrease followed, after the fifth day, by an increase of CO_2 production. In air, the O_2 uptake varied between 7 to 23 mg O_2/kg hr; in 1% O_2, it varied between 8 to 14 mg O_2/kg hr; in 2 % O_2, it varied between 8 to 12.5 mg O_2/kg hr and in 5% O_2, O_2 uptake varied between 11.5 to 15 mg O_2/kg hr .

Ingle (1970) observed similar O_2 consumption rates in strawberries stored in air at 7°C except that the pattern was different. He reported no initial fall in the O_2 uptake during the first 5 days of storage and only noted a rise in consumption after 5 days at 12 °C. Following storage in 2% O_2, Woodward and Topping (1972) noticed off flavors in the berries. Chemical analysis showed accumulation of alcohol in the tissues.

Janes et al. (1978) studied the effects of acetaldehyde and ethylene on the respiration of strawberries harvested at the white stage prior to the onset of color formation. Berries were exposed to 50 ppm ethylene or 5000 ppm acetaldehyde at 22 ^{o}C and respiration was monitored for 25 hours.

Exposure of strawberries to ethylene had almost no effect on the production of CO_2. This verified results reported by Gerhart (1930) and Mason and Jarvis (1970). By comparison, acetaldehyde increased respiration from 52 ml CO_2/kg hr at the start of the experiment to 72 ml CO_2/kg hr 8 hours later.

El Kazzaz et al. (1983) studied the effect of ethylene and carbon monoxide on the respiration rate of strawberries at 0.6^{o}C over 16 days. At a concentration of 20 ppm in air, ethylene did not affect respiration rate until the second week where respiration slightly increased in comparison to fruits held in air. Although it has not much effect on the respiration of strawberry, ethylene may influence the physiology of organisms such as Botrytis cinerea (El Kazzaz et al., 1983).

2.5.4. Relation between respiration and storability

The respiration rate being a mesure of the rate of metabolism, it should in theory, be an index of the rate of deterioration of a product. A lower respiration rate would correspond to a slower deterioration rate and a longer storage life.

In practice, storage life is usually limited by decay and by physiological changes such as softening and dehydration that are not related to respiration. Therefore, storage conditions leading to the lowest respiration rate might not always be the best in extending the product storage life or quality.

For instance, the respiration rate of Cambridge Favourite variety kept in 20% CO_2 is lower at 0 °C than at 3 °C. Yet the fruit kept at the lower temperature exhibited CO_2 injury after ten days while the fruits stored at 3 °C did not until after 30 days (Woodward and Topping, 1972).

Firm fleshed varieties of strawberries will also keep better than soft fleshed varieties although the respiration rate of firm fleshed varieties might be higher than the ones of soft fleshed varieties (Overholser et al., 1931).

2.5.5. Effect of storage conditions on strawberry firmness

Fruits of strawberry cultivars vary in their susceptibility to rotting and are easily bruised by hand picking and transporting, rapidly becoming unmarketable, especially at ambient temperatures. Firmness which is considered to be related to resistance to mechanical injury is often assessed by rubbing the fruit skin with thumb and finger, by penetrometer tests and more recently by sophisticated apparatus such as an Instron which measures both skin strength and firmness (Barritt, 1980, Ourecky and Bourne, 1968).

A firm flesh and tough skin reduce the susceptibility of strawberry to damage at harvesting and indirectly lenghtens shelf life (Barritt, 1980). Ourecky and Bourne (1968) used an Instron to study the strength and firmness of strawberries at different temperatures. On the Instron, the probe speed was set at 50 cm per minute and the probe used was a 0.95 cm diameter star shaped brass probe. The fruits were probed through the side with the stem in the horizontal plane. This produced puncture curve with two and three peaks.

The first peak of the curve was defined as the force required to penetrate the skin. As the probe broke through the skin, a dip in the curve was obtained until the resistance offered by the flesh increased. Some strawberry varieties have a fibrous core while others have a soft or hollow core. Those with a fibrous core produced a puncture force curve with three peaks, the middle being interpreted as the resistance of the cortex to the penetrating probe. Fruits with a uniform flesh and core area gave no second peak. The last peak corresponds to the maximum force required to penetrate the opposite side of the receptacle (Ourecky and Bourne, 1968).

Ourecky and Bourne (1968) observed that as temperature increased, flesh firmness and skin toughness decreased and that the firmer the fruit was, the greater was the effect. The greatest change in firmness occurred between 1 °C and 10°C and the least between 35 °C and 43.5 °C. Flesh firmness was found to influence skin toughness rating.

Fruit size and maturity also had an effect on firmness. Unripe fruits were usually firmer with a tougher skin however the difference between ripe and slightly overripe fruits was small. In general, small fruits were firmer and tougher than medium and large sized fruits; there tended to be no significant difference between medium and large fruits (Ourecky and Bourne, 1968).

Bourne (1982) defined a firmness temperature coefficient (FT coefficient) to describe the effect of temperature on firmness. This coefficient was defined as the percent change in firmness per degree temperature increase over the temperature range studied. Using this formula and data from deformation tests, he found that between 0 to 30 ^{o}C, the percentage decrease in firmness per degree Celcius increase (FT coefficient) was approximately linear but highly variable. For a soft fleshed variety it was equal to 0.46 and to zero for a firm fleshed variety. Between 30 to 45 ^{o}C, the FT coefficient of the short fleshed variety was 3.09 and it was 3.48 for the firm flesh variety.

Bourne (1982) found that the firmness temperature coefficient varied from cultivar to cultivar, from test method to another, from year to year and during storage. Therefore, his results could not be used to predict in advance whether strawberry cultivar will have a low, medium or high FT coefficient.

Plocharski et al. (1978) studied the effect of controlled atmospheres on the flesh firmness and skin toughness of strawberry. Berries were kept at 6 ^{o}C for 4, 8 and 12 days in air; in 16% O_2, 20% CO_2 and 64% N_2; in 1% O_2 and 99% N_2; and in air at 0.1 or 0.05 atmospheric pressure.

After 4 days, he found fruits stored in 20% CO_2 had a marked increase in the texture of both flesh and skin while in the other treatments, the berries kept their original texture. Skin and flesh textures of strawberries kept in 20% CO_2 were 2.1 N and 2.7 N respectively compared to values of 1.5 N and 2.3 N for berry stored in air.

After 8 days, there was 20% decrease in skin toughness and a 30% decrease in firmness for all treatments. After 12 days storage, the toughness and firmness have decreased further and there was no significant differences among treatments. Thus exposure to 20% CO_2 increased mechanical resistance of the skin and of the flesh for up to 8 days.

Plocharsky (1982) further investigated the influence of CO_2 on firmness of strawberry. The effect of the following atmospheres on strawberry firmness were measured; air; 20% CO_2, 1% O_2 and 79% N_2; 20% CO_2, 16% O_2 and 64% N_2; and 1% O_2 and 99% N_2. Berries were stored at 6 °C for up to 10 days. Prior to storage, some berries were exposed to atmospheres composed of 20% CO_2, 16% O_2 and 64% N_2 for 12 to 24 hours. The firmness of the fruits stored in 1% O_2 and 99% N_2 was not significantly different from that of the control. The firmness of fruits stored in 20% CO_2 and 1% O_2 and 20% CO_2 and 16% O_2 were not significantly different. Fruits stored in 20% CO_2 were firmer than the ones stored in air. Fruits exposed to 20% CO_2 for 12 or 24 hours prior to storage in air or 1% O_2 and 99% N_2 were firmer than fruits not exposed.

In a second experiment, Plocharski (1982) verified the effect of 2, 4, 8 and 16 hours exposure to atmospheres composed of 16% O_2, 20% CO_2 and 64% N_2 prior to storage in air at 6 °C for two days.

For ripe berries, a four hour exposure was enough to increase firmness by 8%; a 16 hour exposure increased firmness by 25%. For underripe berries, a 16 hour exposure was required to induce significant differences in firmness. The increase in firmness lasted throughout the two day storage at 6 ^{o}C and for additional day at room temperature. To explain this phenomenon, Plocharski (1982) measured the change in pectic substances and moisture losses during storage.

The greater firmness of fruits stored in 16% O_2 and 20% CO_2 and in 1% O_2 and 99% N_2 could be partly attributed to a significant difference in mass loss during storage. Mass losses in berries stored in 20% CO_2 in air were 2.9% compared to 4.9% in berries stored in air. A few hours exposure to 20% CO_2 and 16 % O_2 followed by storage in air for two days did not cause significant difference in mass losses.

Storage in 20% CO_2 or exposure to 20% CO_2 before storage in air decreased the amount of water soluble fraction and increased the amount of ammonium oxalate fraction of pectic substances. Exposure to 20% CO_2 before storage in 1% O_2 and 99% N_2 did not change the content in water soluble fraction but increased the amount of ammonium oxalate fraction.

The increase in the ammonium oxalate soluble fraction of pectic substances during storage was assumed to be due to an enhancement of the de esterification of pectic substances. Lower activity of hydrogen ions as a result of exposure to 20% CO_2 would promote de esterification. Neal (1965) showed de esterification to have a firming effect on fruit tissue if calcium ions were available. The large differences in sodium hydroxide soluble fraction (not affected by CO_2 treatment) between ripe and underripe strawberries may explain why underripe fruits did not react as much to CO_2 exposure as the ripe ones. The amount of sodium hydroxide fraction in ripe berries was 59 mg/110g and 83 mg/100g in underripe fruits.

Results from the studies cited show that post harvest handling have a significant influence on the quality and shelf life of strawberries. In the field, careful picking followed by rapid cooling to low temperatures preserve fruit quality and reduce fungal growth. Storage in CA suppress fungal growth and to some extent improve strawberry firmness and color. Besides, strawberries stored in CA can be stored longer and once out of storage, they keep better than strawberries stored in RA. The benefits derived from improved post harvest handling of strawberries on strawberry quality and shelf life are the first steps to a broader marketing strategy covering the nation territory.

III. MATERIALS AND METHODS

To study the effectiveness of CA in reducing decay of strawberries of the Red Coat variety, a set of experiment was designed. The quality of strawberries at the end of storage was also studied as well as the residual shelf life after storage.

A factorial design consisting of the following treatments was used:

i) age of the plantation

ii) harvest dates

iii) type of storage

The treatments were replicated four times (Table 4, Table 5).

Statistical analysis of the data was done to evaluate any significant effect of the treatments on the following parameters:

1. percentage of sound berries at the end of storage
2. mass loss
3. moisture content
4. pH
5. acidity
6. skin firmness
7. flesh firmness

In addition, a secondary factorial experiment was carried on berries to verify the effect of a two hour exposure to high CO_2 concentrations on the above parameters (Table 6). This treatment was administered in addition to the other treatments of the storage experiment on berries harvested from one year old fields only.

Table 4. Treatments considered in the storage experiment.

Treatment	Level		
Age of the plantation	one year	or	two year
Harvest date	June 20	or	June 27
Type of storage	RA	or	CA

Table 5. Lay out of the experiment including strawberries from one year and two years old plantation.

```
            HARVEST 1                          HARVEST 2
           /         \                        /         \
   FIRST              SECOND          FIRST              SECOND
   YEAR               YEAR            YEAR               YEAR
   /   \              /   \           /   \              /   \
CA       RA        CA       RA     CA       RA        CA       RA
```

Table 6. Lay out of the experiment including exposure to high CO_2 (only berries from the one year old plantation were used)

```
        HARVEST 1                         HARVEST 2
       /         \                       /         \
   CO2           NO   CO2            CO2           NO   CO2
   /  \           /     \            /  \           /     \
CA      RA     CA        RA       CA      RA     CA        RA
```

A third set of experiment was also conducted to observe the effect of CA on the propagation of mold (nesting) from one berry to the next. This experiment was conducted with berries from the second harvest only.

3.1. Harvesting of the strawberries

Strawberries used in the experiment were of the Red Coat variety. They were grown on a mulched loamy soil rich in phosphorus and potassium (225-279 kg/ha and 335-449 kg/ha respectively). The field was sprayed with 0.1% Benlate 50WP on June 16 and June 23, 1985. Harvesting took place at the Macdonald College Farm on June 20, 1985 and on June 27, 1985. Strawberries were harvested in preweighed experimental containers (3.6 liters capacity plastic jug). Harvesting was done in the morning between 9:00 and 12:00 and 45 berries were placed in the containers. Once filled, containers were put under shade.

The College staff and visitors harvested the strawberry fields thoroughly every two days (Figure 7). Hence the mature berries used for the experiment were no more than two days old. Pickers were instructed to select berries that were sound and firm; preferably at the white tip stage, that is, when 3/4 of the surface is red and the tip is still white in color. Damaged or infected berries were discarded.

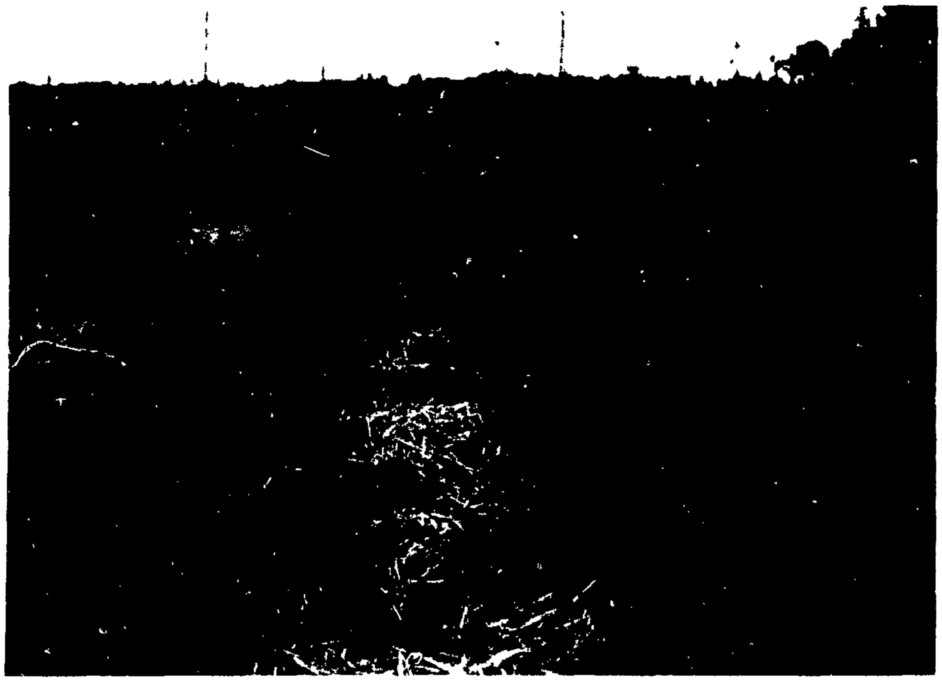

Figure 7. View of the fields at the Macdonald College Farm where strawberries were harvested.

3.2. Treatments

Two hours after the beginning of harvesting, about 35 kilograms of strawberries were taken to the cold room (Envirocon) to be precooled to 5°C in less than two hours. To improve heat transfer, the two circulating fans of the cold room were left running at all times during precooling. Containers were placed in front of the fans so that cold air could circulate around the berries. The temperature of the fruits was measured at the beginning and at the end of the two hour cooling period using a needle probe (thermistor YSI series 700 R 2415-24) connected to a YSI thermometer (series 8400). The temperature was measured at the center of the containers. During storage, temperature in the cold room was kept at 5°C +/- 1°C.

After precooling, the experimental containers were weighed. After weighing, a lid was loosely fitted on containers to be used for the regular atmosphere treatment (RA). Containers to be used for the CA treatment were tightly capped with a lid equipped with a gas inlet, a gas outlet and a septum (Figure 8). The gas inlets were connected to a gas distribution network delivering approximately 60 CC/min of a mixture of 16% CO_2 in air to each container.

To bring the gas composition in the storage chambers to the level desired, the containers were flushed with a gas mixture composed of 16% CO_2, 20% O_2 and 64% N_2 for 10 minutes at a rate of 400 cc/min per container. Gas analysis was done after flushing and containers with too low carbon dioxide content were flushed again 5 to 10 more minutes until the gas composition in the container was satisfactory.

Gas within the containers was sampled through a septum installed on the lid (Figure 9). A one cc syringe fitted with a 22.2 mm needle (Becton Dickinson, model 25G7/8) was used to sample the gas. After sampling, the syringe was placed into a rubber stopper to prevent any gas contamination or loss to and from the atmosphere. Gas analysis was done within minutes using a Fisher Hamilton gas partitioner (model 29). The gas partitioner had been previously calibrated using a gas mixture composed of 10.6% CO_2, 4.97%O_2 and 84.43% N_2. Results were recorded using a Hewlett Packard integrator (model 3390 A).

Once the desired atmosphere was reached in a container, it was flushed continuously at a rate of 60 cc/min using a mixture of gas supplied by a gas cylinder. The mixture was done at the plant of Liquid Carbonic and was for technical use (precision of +/- 2% in the concentrations). Differences in CO_2 concentrations from one gas cylinder to the next were considered acceptable as long as the concentrations in the experimental containers were maintained between 15 and 20%. The composition of the gas mixture was 18 % +/- 2% CO_2, 19 % +/- 2% O_2 and 63 % +/- 2% N_2.

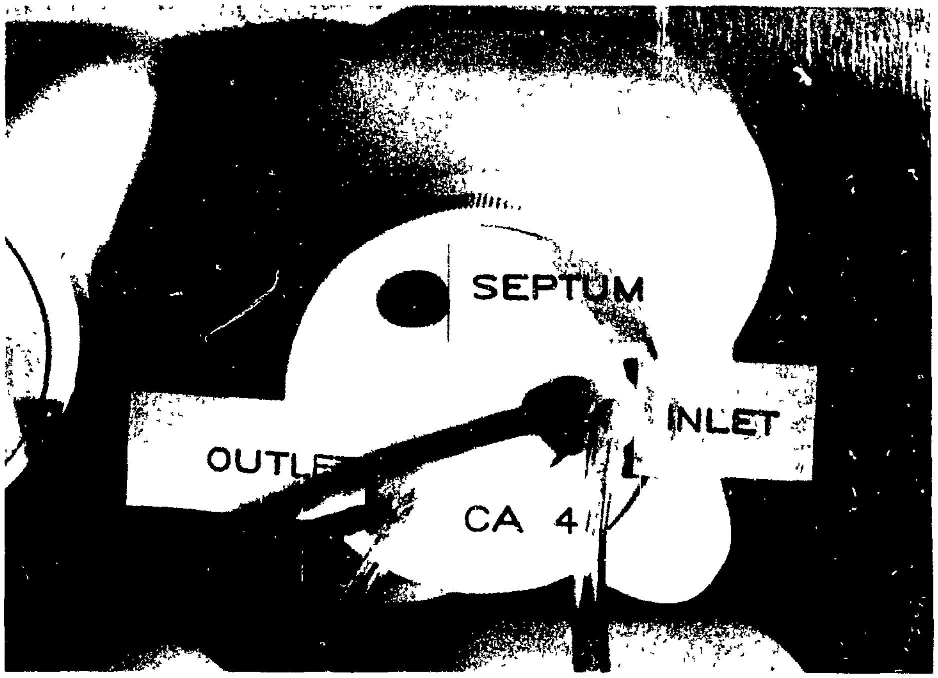

Figure 8. The experimental containers were capped with a lid equipped with a gas inlet, a gas oulet and a septum.

Figure 9 . Gas within the container was sampled via the septum using a 1 cc seryngue.

Gas composition in each container was monitored daily following the method described above. Excessive variation in gas composition were usually corrected by tightening the lids, fixing loose junctions in the distribution network and flushing each container(s) with a 100 cc/min of the gas used to create the CA conditions. Usually, concentrations returned to desired levels within a half hour. The gas distribution network as well as the container inlets and outlets were made of a 0.635 cm (outside diameter) plastic tubing (Tygon) fitted together using high density polyethelyne fittings (Figure 10). The distribution network brought gas to the 8 containers (Figure 11). Any spore contamination from a container to the other via the distribution network was prevented by maintaining a positive pressure in the network relative to the containers.

To have a more balanced flow in all containers, gas was introduced in the distribution network via two inlets. (Figure 12). Gas flow in the distribution network was controlled and monitored via a precision flowmeter (Union Carbide model FM-4202). The gas mixture was supplied from a high pressure cylinder (size K) (Figure 13). The cylinder was rolled prior to connecting it to the system to make sure gases inside were well mixed. The gas cylinders were kept in the cold room so that the gas temperature was the same as that of the berries. A two stage regulator equipped with a manifold was used to regulate the pressure and to direct the gas to the gas distribution networks.

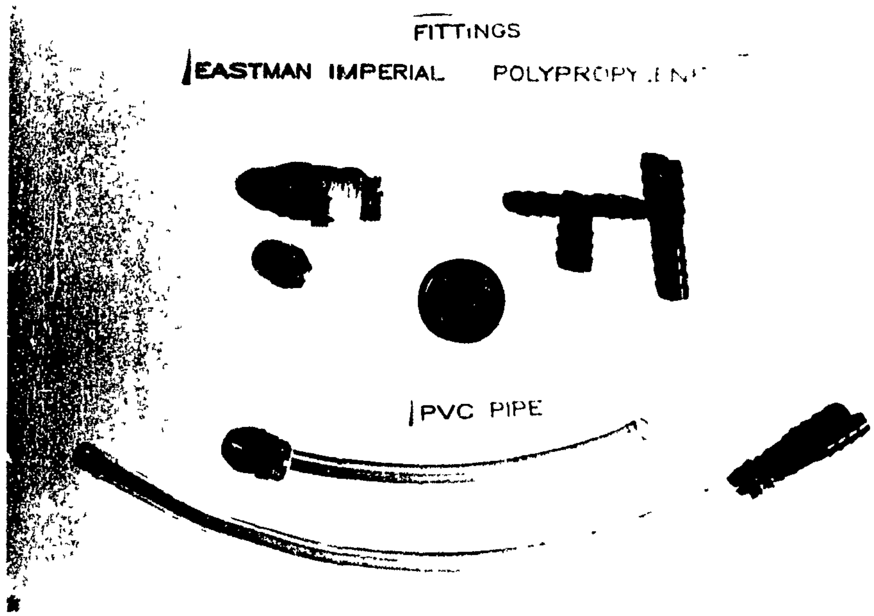

Figure 10. Polyethylene fittings used to assemble the gas distribution network.

Figure 11. The gas distribution network brought a 100 cc/min of gas to up to 8 containers.

The manifold consisted of 0.635 cm copper plated iron tubing (unknown manufacturer) with a 0.635 cm NPT thread and held together by fittings also made of copper plated iron (Figure 14). Eight valves were installed on the manifold constructed and were used to allow or to shut gas flow to a given distribution network. A three meter long 0.635 cm O.D. polyethylene tubing connected the manifold to the flowmeter of each distribuiton network. The tubing was held to the manifold by means of Eastman Imperial fittings.

3.3. Measurements

At the end of the storage experiment, the experimental containers were weighed. The initial and final masses were used to compute the percent mass losses during storage. The method suggested by Ourecki and Bourne (1968) was followed to measure strawberry texture. The Instron was calibrated so that a one kilogram load (9.8 N) caused a 25.4 cm horizontal deflection of the pen. A 0.32 cm diameter probe secured on the upper plate of the Instron and travelling at a speed of 10 cm/min was used to puncture the berries. The chart speed was set at 20 cm/min. The edge of an eraser was used to support the fruit during testing to prevent it from rolling or changing position. The berries to be tested were left at room temperature (22 +/- 2 ^{o}C) for three hours to warm up. A needle probe connected to a YSI thermometer was introduced in some of the berries to check if they had reached room temperature.

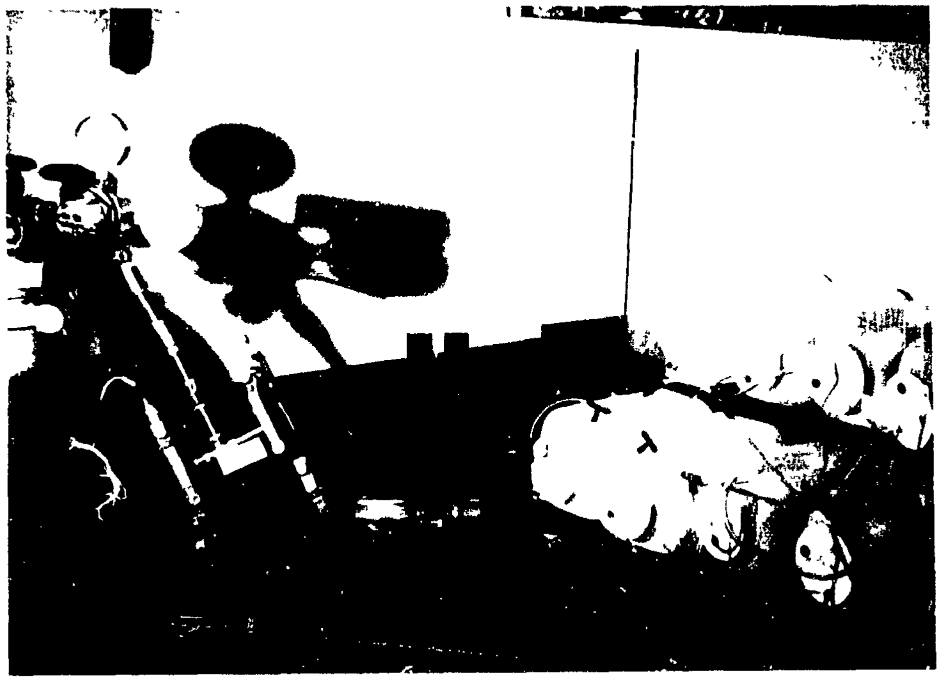

Figure 13. Gas supply system. A gas tank equipped with a two stage regulator supplies an 8 port manifold used to route the gas to distribution networks. A flowmeter monitors and controls the gas flow to each network.

Figure 14. The manifold was equipped with ball valves used to cut or allow the flow of gas to a particular distribution network.

During testing the Instron probe travelled through more than half the fruit to obtain the desired two peak curve. The first peak corresponded to the toughness of the skin; the second to the firmness of the flesh. We weighed and tested 15 strawberries for each replicate.

The acidity tests, the moisture content and the soluble solids were carried on the berries used for firmness tests. The quality tests were carried less than two hours after the firmness tests were completed. The fifteen berries of a given treatment were cleaned and cut into quarters. One quarter was assigned to acidity tests, another to soluble solids determinations, a third to moisture analysis and the last was frozen or kept as a spare in the event a test would have to be redone. For each test, the 15 quarters were put together in a composite sample from which three sub samples weighing 8 to 10 grams were drawn for analysis. For the acidity tests, the procedure suggested by the A.O.A.C. (1980) for the analysis of fresh fruits was followed. The results were expressed as per cent citric acid. Soluble solids determinations was done following the method suggested by the A.O.A.C. (1980). Juices extracted from the berries were filtered through a paper filter before placing in the Abbé refractometer. Once the readings were taken, the refractometer window was cleaned using 100% ethanol. The results were expressed as per cent soluble solids.

To find the moisture content, the samples were dried in an oven set at 43°C until no weight change was recorded (usually two days).

3.4. Simulation of commercial storage conditions

At the end of each storage experiments, the strawberries in the experimental containers were inspected for visible signs of spoilage (foul odors, molds, discoloration). When none was recorded, the strawberries left were submitted to an experiment aimed at simulating marketing conditions at the retail level.

Strawberries marketed in retail stores are usually sold at room temperature. At the end of the day, the unsold strawberries are stored in cold rooms usually set at 10 °C. A simulation of the commercial marketing conditions is included at the end of storage to verify the residual shelf life of strawberry. Storage of fresh strawberries would be useless if the berries are spoiled once out of the cold room. The experiments simulating commercial storage conditions were conducted in a cold room (Envirocon) kept at 10 +/- 2°C. The inside of the room was kept dark except when berries were sampled or transferred outside. The berries were stored in uncapped experimental containers.

Storage under commercial conditions lasted for two days. Every twelve hours, the berries were taken out of the cold room and stored at room temperature (22 +/-2 °C). After 12 hours at room temperature, the containers were stored back in the cold room. This cycle continued for two days. At the end of the period, the percentage of marketable strawberries was recorded (to be later converted in the parameter called percentage of sound berries for statistical analysis). Samples of molds present were taken for isolation and identification (see Appendix B).

3.5. Exposure to High CO_2 concentrations

A second set of experiment was conducted to evaluate the effect on quality and shelf life of strawberries of a two hour exposure to CO_2 concentrations above 60%. This set of experiment was carried only with strawberries harvested from the one year old plantation. It was repeated for both harvests. The same experimental procedure, similar to the storage experiment, was followed for these experiments except for the additional treatment of high CO_2 exposure which took place during precooling.

Fruit containers to be exposed were capped with plastic lids, fitted with a septum, a gas inlet and a gas outlet, as soon as they were brought in the cold room. They were then flushed with pure gaseous carbon dioxide until the gas composition within the container was at least 80% CO_2. This higher initial CO_2 concentration was set to offset gas losses through leaks during the two hour exposure. Gas analysis was done after flushing for 15 minutes at a flowrate of at least 400 cc/min per container. Containers with too low carbon dioxide content were flushed again 5 to 10 more minutes until the gas composition in the container was satisfactory. The method described in the section on the storage experiment was used to sample the atmosphere in the containers. At the end of the exposure period, all lids were removed from the containers.

Strawberries were visually inspected for possible carbon dioxide injury. Foul odors were also checked.

This experiment was included to approximate conditions that would exist in a precooler where liquid CO_2 would be used as a refrigerant. Liquid CO_2 or N_2 are popular refrigerants in precoolers with a short operating season because systems equipped this way required little maintenance and capital investment (Rohrback et al., 1984). In addition, the refrigeration capacity can be very large. The use of cryogenic gas implies anaerobic or near anaerobic conditions will prevail in the precooler when it is operating. This might have an effect on strawberry flavour or quality (Ballinger, 1980).

3.6. Effect of CA on mold propagation (nesting)

An experiment was carried to check the effectiveness of the gas mixture used for the CA treatment of the storage experiment in controlling nesting or the growth of mycelium from a rotting berry to infect nearby sound fruits in the container (El Kazzaz et al., 1983). For this experiment, only strawberries from the second harvest were used. After precooling to 10°C, 700 grams of strawberries were placed in two liter transparent plastic containers. A decaying strawberry inoculated with Botrytis cinerea was placed in the middle of the container so that mold invasion could be observed. Four replicates were made in normal atmosphere or in CA (16% CO_2, 20% O_2 and 64% N_2). The containers were left at room temperature for 24 hours. Photographs of the molded strawberries were then taken. A second set of photographs showing the degree of spoilage in each container was taken at the end of the experiment (36 hours later). The presence of fungal infection (filaments) on fruits was noted.

IV. RESULTS AND DISCUSSION

The results of three experiments conducted in this study on the CA storage of strawberries are presented in this section. They are;

i) effectiveness of CA storage in reducing decay and its effect on berry quality.

ii) effects of a two hour exposure to atmospheres high in CO_2 on flavor, color and keeping quality of berries.

iii) nesting experiment to assess disease propagation in different storage conditions.

The observations from the experiment on the influence of high CO_2 exposure will be useful to generalize results from the storage experiment. Further the experimental results will contribute to arrive at recommandations to improve the strawberry handling and to obtain some indications about the cost effectiveness of the proposed methods.

4.1 Evaluation of the Experimental Conditions.

Concentrations of O_2 and CO_2 inside the containers were monitored during the storage experiments (Table 7). In the first experiment (started on June 20), there was larger variations in gas concentrations. The variations, however, were within the acceptable levels selected for the experimental design.

Table 7. Average daily O_2 and CO_2 concentrations in experimental containers used for CA treatment.

GAS	Experiment 1	Experiment 2
O_2	20 +/- 1.5%	20 +/- 1%
CO_2	16 +/- 1.5%	16 +/- 1%

At the start of each experiment, the initial quality of strawberries was evaluated (Table 8). Strawberries from the second harvest were smaller in size than strawberries from the first harvest. The pH, moisture content and firmness of the skin were about the same in fruits from both harvests. The average pH was 3.5, the average moisture content was 88.9% and the average firmness of the skin and of the flesh were respectively 2.3 Newtons (N) and 4.8 N for berries from the first harvest and 2.6 N and 3.8 N for berries from the second harvest. These results for moisture content, pH and firmness of the skin compared well with results from other studies (Skrede, 1980, Woodward, 1972, Ourecky and Bourne, 1968).

The average acidity and average SS measured for strawberries from harvests 1 and 2 were respectively 0.88%, 10.0% and 1.04%, 10.5%. The acidity and SS content measured were comparable to those cited in the literature (Money and Christian, 1950, Woodward, 1972). The acidity was greater in strawberries from the second harvest than in berries from the first harvest. The acidity value indicates strawberries from the second harvest to be less ripe than those from harvest 1. The SS to acid ratio is 11.4 for strawberries for harvest 1 compared to 10.1 for berries for harvest 2 indicating strawberries from harvest 1 to be more mature.

Table 8. Chemical and physical analysis of fresh strawberries at harvest.

Parameters	Harvest one	Harvest two
% moisture	89.9 +/- 0.3	88.9 +/-0.8
pH	3.48 +/-0.07	3.49 +/-0.09
acidity (%)	0.9 +/- 0.3	1.0 +/- 0.08
Mass (g)	16.2 +/- 2.3	10.4 +/- 1.5
SS (%)	10.0 +/- 0.5	10.1 +/- 1.1
Firmness		
Skin (N)	2.3 +/- 0.2	2.6 +/- 0.5
Flesh (N)	4.8 +/- 0.3	3.8 +/- 0.7

Values listed are the average of 8 readings. Standard deviations are shown.

The first set of experiments considered the effects of harvest dates, year of plantation and type of storage on the quality and shelf life of strawberries. The GLM procedure was used to analyse the data. The complete tables of the statistical analysis performed on the data of the storage experiment are presented in Appendix C. The data expressed as a percentage (for example, per cent soluble solids) were converted into their transformed value (arcsin (square root (X/100))) to stabilize the variance according to the method suggested by Dr^per and Smith (1981).

The year of plantation had a significant influence on the initial mass of berries. But the harvest date had a significant effect on mass loss, initial mass of the berries, skin and flesh firmness and SS (Table 9). Further the type of storage had a significant influence on the percentage of sound berries and on the percentage soluble solids. The significance of the main effects and interactions are also shown in Table 10.

4.2. Influence of the Year of Plantation on the Quality and Shelf Life of Strawberries.

The year of field plantation had little effect on strawberry keeping quality (Table 10). It was initially hypothesized that possible difference in maturity (fruits from older plants mature faster because their root systems are better established) or field infestation would influence the keeping quality of strawberries . As no such effect was observed, it is recommended that for storage

Table 9 . Significance of the treatments for the parameters studied in the storage experiment. (ANOVA are listed in Appendix C)

Parameters	Probability	Source of variation
% sound	0.0001	storage storage-harvest-year interaction
% mass loss	0.0001	harvest harvest-year interaction harvest-storage interaction
% moisture	0.1589	None
pH	0.1281	None
% acidity	0.1383	None
Mass (g)	0.0001	harvest year
% SS	0.0131	storage storage-year interaction
Firmness		
Skin (N)	0.0106	harvest year-harvest interaction year-storage interaction
Flesh (N)	0.0026	harvest

Table 10. Influence of year of plantation on strawberry quality and shelf life.

Parameters	Treatments	
	Year one	Year two
% sound	71a	66a
% mass loss	1.4a	1.4a
% moisture	88.9a	89.4b
pH	3.49a	3.50a
% acidity	0.93a	1.00a
Mass (g)	14.3a	11.7b
% Soluble solids	9.4a	9.9a
Firmness (N)		
Skin (N)	3.5a	3.4a
Flesh (N)	5.3a	4.9a

Means of four replicates per treatment. Within each column, means with a common letter are not significantly different according to Tukey's studentized range test (P = 0.05).

experiments, there is no need to discriminate strawberries picked from fields planted on different years .

The moisture and initial mass of strawberries picked from fields planted on different years were found to be significantly different. The pH, the acidity and the soluble solid content were not significantly different whether the berries were harvested from one year old or two year old fields. This is unlike Sweeney et al. (1970) who observed strawberries grown the first year to be higher in SS than those grown the second year. The differences between Sweeney et al. (1970) results and ours is likely due to strawberry varietal differences.

There was no significant difference between the skin and the flesh firmness of strawberries harvested from one or two year old fields.

4.3. Influence of Harvest Dates on Quality and Shelf life of Stored Strawberries

There was no significant influence of harvest date on the moisture content, acidity, SS content after 10 days of storage and on the percentage of sound strawberries after 2 additional days of storage under commercial conditions (Table 11). However, harvest date had a significant influence on the mass loss, pH, mass, and skin and flesh firmness of strawberries stored for 10 days.

Table 11. Influence of harvest dates on strawberry quality and shelf life.

Parameters	Treatments June 20	June 27
% sound	68%a	68%a
% mass loss	1.8%a	1.0%b
% moisture	90.0%a	89.3%a
pH	3.53a	3.46b
% acidity	0.94%a	0.99%a
Mass (g)	15.5a	10.5b
Soluble solids(%)	9.6a	9.6a
Firmness (N)		
Skin (N)	3.6a	3.3b
Flesh (N)	5.7a	4.5b

Means of four replicates per treatment. Within each column, means with a common letter are not significantly different according to Tukey's studentized range test (P = 0.05).

The time of harvesting had little influence on keeping quality of strawberries. In our study, it was hypothesized that strawberries picked later in the season would be more prone to decay because of higher field infestation. However the results indicated the time of harvesting had little influence on keeping quality of strawberries. Working with a different cultivar (Cambridge Favorite), Dennis and Mountford (1975), Dennis (1978) and Browne et al. (1984) observed a greater susceptibility and a shorter shelf life in strawberries harvested late in season. For instance, after storage at 2 °C for three days in RA or in CA (10% CO_2, 14% O_2), strawberries harvested early in season had a two to three days shelf life when left at 15 °C while strawberries harvested two weeks later spoiled within hours (Browne et al., 1984). Browne et al. (1984) and Dennis (1978) attributed the shorter shelf life of berries harvested late in season to higher incidence of B. cinerea and M. piriformis at the time of harvest. At the first harvest, infection affected 1% of the berries while at the third harvest, 6% of the berries were infected.

Little variation in the level of field infection, greater resistance to fungal attack for the Red Coat variety and a shorter harvesting interval are possible explanations to account for the difference between what we observed and what the researchers cited observed. In our experiment, the level of infection present in the field at harvest time was not measured.

Mass losses were significantly higher for berries from harvest 1 than for berries from harvest 2. Berries from harvest 1 being significantly greater than berries from harvest 2, they might have lost more water because of their larger surface area. Additional data on surface to volume ratio would be required to substantiate this explanation. However, Woodward (1972) reports that for strawberries, mass or moisture losses are rarely a problem during storage.

There was a significant difference in pH between strawberries of different harvests at the end of storage. The SS to acidity ratio indicates berries from the first experiment (ratio of 10.2) are more mature at the end of storage than the berries from the second storage experiment (ratio of 9.7). As mature fruits tend to be less and less acid as they ripe, it might explain the difference in pH observed in berries from both harvests.

At the end of the storage experiment , the skin and the flesh of the strawberries from the first harvest were significantly firmer than the flesh of berries harvested later. The average firmness of the skin and the flesh were respectively 3.6 N and 5.7 N for strawberries picked on the first harvest and 3.3 N and 4.5 N for berries from the second harvest. Those results are comparable to the ones of Ourecky and Bourne (1968) who found the firmness of the skin and flesh of strawberrries of the Red Coat variety to be 2.5 N and 5.7 N. Ourecky and Bourne (1968) found that the firmness of the underlying tissue was related to the skin firmness as shown by a correlation of 0.764 between the two parameters.

Our results indicate that larger fruits have firmer skin and flesh. This is unlike Ourecky and Bourne (1968) who found the skin and the flesh of small fruits to be firmer. Monma and Kamimura (1979) found a relation between mass loss and skin firmness. They observed fruits with larger mass loss were less firm. Our observations do not agree with those results.

In our opinion, the lack of a standard procedure for firmness tests limits the validity of comparison with the studies cited. Ourecky and Bourne (1968) recognized that the speed of travel, the size and the shape of the probe, the temperature of the berry influenced the results recorded. For simplicity sake and to facilitate the replication of experiments , the probe used for the firmness tests should have a simple shape, easily defined and reproduced. Unless there is a reason justifying another shape, we recommend using cylindrical probes that are easily manufactured knowing only their diameter. Complicated shapes, such as the star shaped probe used by Ourecky and Bourne (1968), are defined by many parameters (inner and outer diameters of the star, length and number of each branches) and machining is required to produce the piece.

4.4 Effect of storage in RA and CA on strawberry shelf life and quality.

Storage conditions had a significant influence on soluble solids, firmness of the flesh and skin and decay (% sound) of strawberries (Table 12). There was significantly less decay in strawberries stored under CA than in berries stored under RA. The SS content of strawberries stored under CA was significantly lower than when berries were stored under RA. The firmness of the flesh and of the skin were significantly larger in strawberries stored under CA than in berries stored under RA. In this study, no significant difference in moisture content, mass loss, pH and acidity were observed.

Storage in CA significantly reduced decay (% sound) in stored strawberries. Storage in CA had no detectable effect on taste or smell. We noticed the color of the strawberries stored in CA was brighter than those in RA. Besides improving shelf life, storage in CA seems to improve the appearance of the product and makes it look fresh.

Reduction in losses of 20% or more when strawberries are stored in CA are also reported by Kazzaz et al. (1983) and Lange et al. (1978). El Kazzaz et al. (1983) reported 0.15% loss in strawberries stored for 21 days at 3.3°C in 15% CO_2, 17.5% O_2 and 67.5 % N_2. Lange et al. (1978) stored strawberries at 6 °C for 8 days in 20 % CO_2, 16% O_2 and 64% N_2 and observed 0.1% loss compared to 20% in RA.

Table 12. Influence of the type of storage on strawberry quality and shelf life.

Parameters	Treatments	
	Storage in RA	Storage in CA
% sound	55a	80b
% mass loss	1.4a	1.4a
% moisture	88.8a	89.5a
pH	3.50a	3.50a
% acidity	0.96a	0.96a
Mass (g)	12.7a	13.4a
%Soluble solids	9.9a	9.4b
Firmness (N)		
Skin (N)	3.3a	3.6b
Flesh (N)	4.9a	5.3b

Means of four replicates per treatment. Within each column, means with a common letter are not significantly different according to Tukey's studentized range test ($P= 0.05$).

Strawberries stored in CA have a significantly lower SS content than the ones stored in RA. Borecka and Millikan (1981) found no consistent difference in SS or in titratable acidity that could be associated with the type of storage used. As there is no consistent relation between these parameters and storage conditions, they are a poor indicator of the possible influence of storage conditions on the maturity of strawberries. The ratio of the SS over the acidity content is used for other small fruits, such as blueberries, to assess their maturity (Ballinger, 1980).

The flesh and skin of strawberries stored in CA were significantly firmer than berries stored in RA. The increase in firmness was about 10%. These results agree with the ones of Plocharski et al. (1978) and Plocharski (1982) who found a 20% increase in firmness when strawberries (Senga Sengana variety) were stored in 20% CO_2 and 16% O_2 for 8 days. When strawberries were stored for 12 days, he observed a decrease in firmness. We did not measure the evolution of the firmness of the strawberries while the experiment was in progress and it might have to decreased at some point. Shorter storage periods might therefore be advisable.

4.5. Influence of Exposure to High CO_2 Concentrations on Strawberry Quality and Shelf life.

Data on the gas concentrations at the beginning and at the end of the treatment where strawberries were exposed to high CO_2 concentrations are presented in Table 13. Exposure to concentrations between 60 to 80 % CO_2 for two hours did not cause any visible damage to the strawberries and no off flavors were detected after the exposure.

The following experiment considered the effects of harvest dates, type of storage and exposure to high CO_2 concentrations on the quality and shelf life of strawberries. A factorial analysis was done using the SAS statistical system following the general linear model (GLM) procedure. The complete results of this analysis can be found in Appendix C.

Table 13. Average initial and final carbon dioxide concentrations in containers used for exposing strawberries to atmospheres with high CO_2 concentrations.

Harvest	Treatment	CO_2 concentrations initial %	final %
HARVEST 1	CA	81	64
	CONTROL	84	61
HARVEST 2	CA	85	55
	CONTROL	84	58

The type of storage was found to have a significant effect on the percentage of sound berries, mass loss and skin and flesh firmness (Table 14). The harvest dates had a significant influence on mass loss, mass, and skin and flesh firmness. Short exposure to high CO_2 concentrations had a significant influence only on the firmness of the flesh.

Interactions among the three treatments had a significant effect on percentage of sound berries (Table 14). Interactions between harvest dates and storage had a significant effect on flesh firmness. Interactions between harvest dates and exposure to high CO_2 had a significant effect on decay (% sound) and skin and flesh firmness. Interaction between storage and exposure to CO_2 had a significant effect on mass.

Exposure of strawberries to atmospheres with high CO_2 concentrations had no significant effect on strawberry quality except for a significant increase in flesh firmness (Table 15). Plocharski (1982) also observed an increase in firmness of strawberries following exposure to high CO_2 concentrations.

Exposure for two hours to atmospheres containing high CO_2 concentrations had no significant influence on decay nor on quality. This means liquid gas could be used to precool the berries without causing off flavors or affecting the appearance of the fruits. Firmness of the flesh appears to be significantly increased by short exposure to high CO_2 which may help in preventing bruising and associated decay.

Table 14. Significance of the treatments for the parameters studied in the high CO_2 experiment. (ANOVA are listed in Appendix C)

Parameters	Probability	Source of variation
% sound	0.0001	storage harvest-CO_2 interaction storage-harvest-CO_2 interaction
% mass loss	0.0093	storage harvest
% moisture	0.1523	None
pH	0.0967	None
% acidity	0.2694	None
Mass (g)	0.0001	harvest storage-CO_2 interaction
% SS	0.7744	None
Firmness		
Skin	0.0001	storage harvest harvest-CO_2 interaction harvest-CO_2-storage interaction
Flesh	0.0007	storage CO_2 harvest storage-harvest interaction CO_2-harvest interaction

Table 15. Influence of exposure to high CO_2 on strawberry quality and shelf life.

Parameters	Treatments: No exposure	Treatments: With exposure to CO_2
% sound	71a	66a
% mass loss	1.2a	1.4a
% moisture	88.8a	88.8a
pH	3.5a	3.5a
% acidity	0.92a	0.98a
Weight (g)	14.7a	14.3a
%Soluble solids	9.3a	9.3a
Firmness (N)		
Skin (N)	3.5a	3.6a
Flesh (N)	5.3a	6.0b

Means of four replicates per treatment. Within each column, means with a common letter are not significantly different according to Tukey's studentized range test (P = 0.05).

4.6. Effect of CA on the Loss of Aroma and the Propagation of Mold

Strawberries stored in CA can be kept for fairly long period without appreciable loss of quality. Strawberries have been stored up to 21 days in CA with little losses recorded (El Kazzaz et.al., 1983). In some situations, the limiting factor to the length of storage seems to be the loss of flavors with time . Varieties with strong aroma in particular lose their flavor rapidly and although sound at the end of storage, they are not as tasty (Smith, 1938). The storage and high CO_2 experiments did not last long enough to observe any detectable loss of flavors in stored strawberries.

The inhibiting effect of CA on sporulation of Botrytis cinerea was verified in the nesting experiment and is clearly shown in Figure 15 and Figure 16. Strawberries in the container on the left were stored in CA while those in the container on the right were stored in RA. There is no visible filament growth on the spoiled strawberry stored in CA while in RA filaments have begun to invade nearby sound strawberries. The white spots present on the picture is due to poor processing when the film was developed.

The retarding effect of CA on the growth of molds is well demonstrated in Figure 17. This picture was taken at the end of the nesting experiment and shows the extent of spoilage after 60 hours in containers maintained at 20 ^{o}C in RA (upper container) or in CA (lower container). Strawberries stored in CA shows minimal signs of decay: discoloration of the surface, white filamentous growth (Figure 18). By considering only their appearance, strawberries in the CA container could still be sold. Upon opening of the container, some foul odors were present indicating some fermentation has occurred. Strawberries also had strong off flavors. This shows cold temperature storage is required with CA if the quality of the strawberries is to be maintained. Storage in CA will control decay organisms but will not control biochemical reactions related to the metabolism of the fruits.

Strawberries stored in RA for 60 hours at room temperature are unmarketable (Figure 19). Many berries are completely spoiled and have begun to leak.

Storage in CA can stop the spread of infection from one berry to another as demonstrated in the nesting experiment. Bruised or overripe berries can thus be stored for some time in CA without spoiling; an advantage which the storage in RA does not offer.

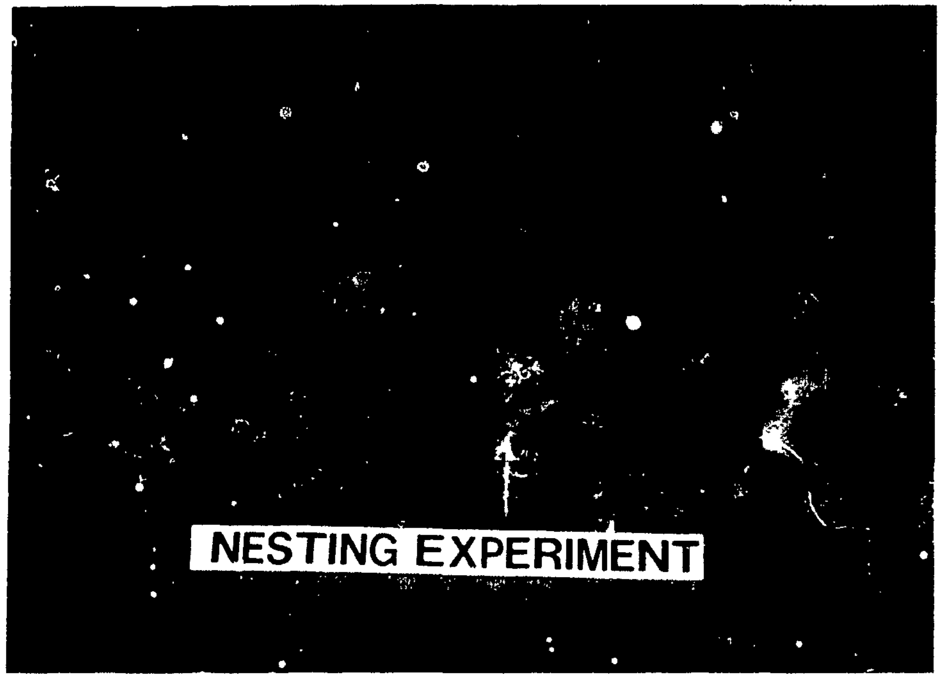

Figure 15. Storage in CA inhibits the growth of Botrytis cinerea . The spread of infection from the spoiled strawberry is stopped in the container on the left. Strawberries located next to the spoiled strawberry are being colonized in the container on the left. White spots present on the picture are a result of poor processing when the film was developed.

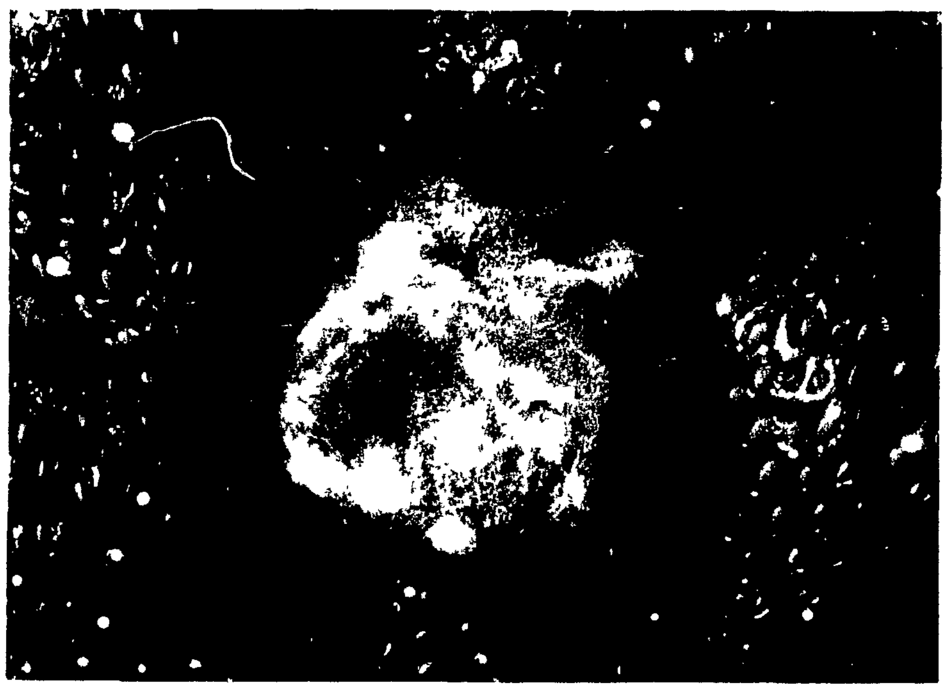

Figure 16. Storage in CA inhibits the spread of infection by inhibiting sporulation and the development of hyphae for Botrytis cinerea.

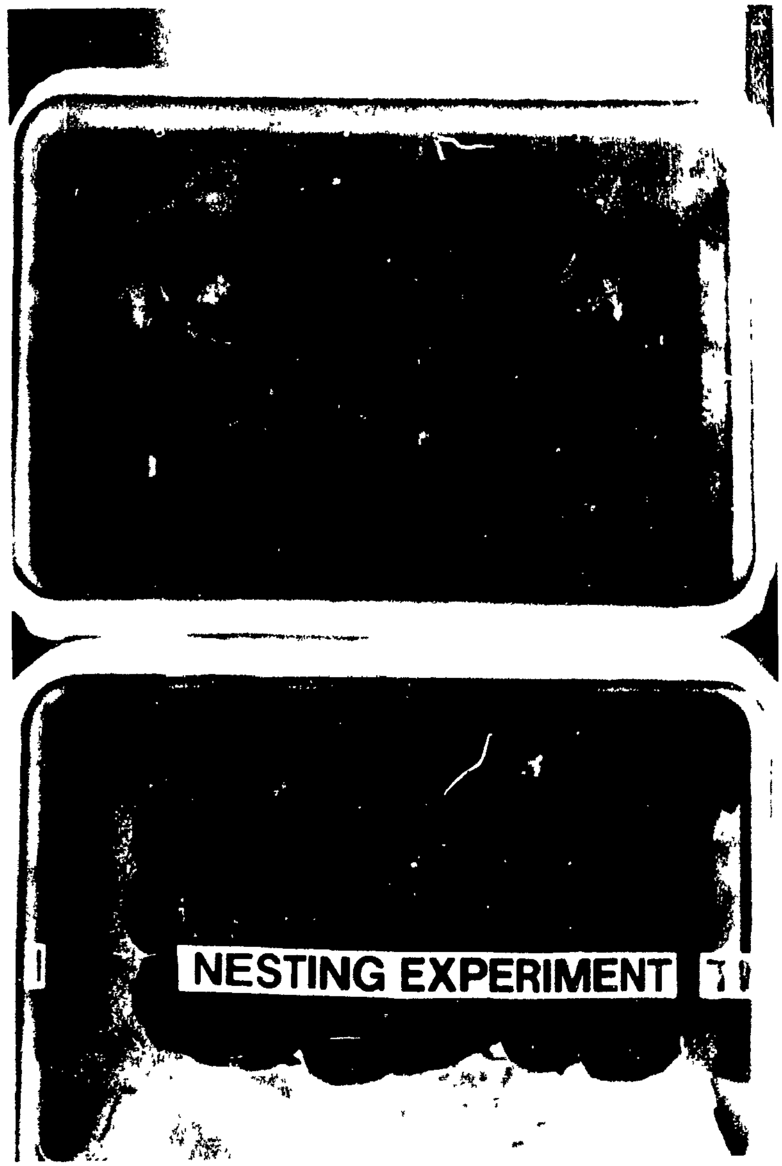

Figure 17. The strawberries in the upper container were kept in RA at 20 °C for 60 hours. Most berries are spoiled. The berries in the lower container were stored in CA. Visible signs of spoilage are much more limited.

Figure 18. Strawberries stored in CA at 20 °C for 60 hours shows some signs of spoilage: discoloration of the skin, whitish filaments growing on the receptacle.

Figure 19. Most strawberries stored in RA at 20°C for 60 hours have began to spoil.

V. ECONOMICS

Precooling and CA storage are effective means of preventing spoilage of strawberries. Their use in Québec is very limited because most producers believe they cannot afford the investment for the equipment taking into account the small volume of strawberries they produce. In Québec, 52% of the producers (500 operations) cultivate less than 1.2 hectares (3 acres), 31% (300 operations) cultivate less than 4 hectares (10 acres) and 17% (160 operations) cultivate more than 4 hectares (10 acres) (Girard, 1985).

Small producers sell most of their harvest to the consumers through pick your own operation. Larger producers market a significant part of their harvest through distribution channels and they would be the ones primarily interested in precooling and CA storage. According to Lafleur (1985), 15 % of the harvest delivered at the retailer level is unmarketable while 44% is bruised. Given an annual production of 9 000 tons worth an estimated $ 11 millions, spoilage alone would account for losses of 1 350 tons leading to $1.65 millions.

5.1. Investments Required for Precooling.

If they were aware of the benefits, more than 460 producers would be using precoolers and CA storage while handling their crops from the field to the store. A preliminary evaluation of the investments and the benefits that can be drawn from these methods will be presented in this section.

According to Berthelot (1984), the average yield of strawberry is about 9 400 kg/ha (8 400 lb/acre), the fields are harvested over a period of 14 days and the average price paid at the farm is \$1.20/kg (\$0.55/lb). Given a producer harvesting 5 hectares of strawberries and selling half of its production directly to the consumers, this would leave 23,500 kg (51 807 lbs) of berries to precool. Given the 14 days harvest period, there would be an average of 1 678 kg/day (3700 lbs/day) to precool from 25 ^{o}C to $5^{o}C$.

If precooling is to take place in two hours including handling and there are 12 hours available to precool, this means the unit would have to precool 140 kg/hr (310 lb/hr). According to Rohrbach et al. (1984), one kilogram of liquid CO_2 is required to cool 2.5 kg of blueberries by $20^{o}C$. Based on this figure, 56 kg/hr of liquid CO_2 would be necessary to cool the harvest. At a cost of \$ 0.40 per kilogram of CO_2 (rental of the canister included), the cost of CO_2 per kg cf berries would be \$ 0.16. This represents 13 % of the selling price of the crop.

A mechanical refrigeration system could be used instead of liquid gas to precool the berries. Given a specific heat of 3.8 KJ/kg ^{o}C (0.9 BTU/lb ^{o}F), neglecting the other sources of heat (respiration, heat gain through the walls of the precooler, etc.), and cooling the harvest by 20 ^{o}C, a total of 10 600 KJ/hr (19 000 BTU/hr) would be removed. A refrigeration system with a capacity of 2 tons (2.3 KW) would be sufficient to cool the harvest. The hourly cost of the electricity to operate the system would be negligible ($0.10).

The cost of energy of a precooler is higher when liquid gas is used as a refrigerant. However, the acquisition cost of a precooler working with liquid gas is estimated at one fourth of the one of a conventional cold room (Belzile, 1986). A conventional cold room with a refrigeration capacity of 2 tons and a storage capacity of 18 m^3 would cost $ 8 500 .

The handling of strawberries in crates of 10 pints (4.5 kg) in and out of the precooler requires approximately one minute. Given a total of 23 500 kg to handle in the season and wages of $7.00 an hour, the manpower required to handle the crop in the precooler would cost around $ 600.00.

If the investment in the precooler is to be recovered within five years, the cost of cooling strawberries would be $ 0.097 per kilogram if a mechanical refrigeration system is used and $ 0.203 if liquid gas is used (Table 16). With time and neglecting the maintenance cost of a mechanical refrigeration system, the precooler operating with liquid gas is twice as expensive to own and operate as the mechanical system. If strawberries are sold at $ 1.20/kg, the cost of mechanical precooling is 8% which is reasonable. The Québec Ministry of Agriculture and Agriculture Canada have plans available to build precoolers (Figure 19, Figure 20). The units suggested are add ons to existing cold rooms. The preliminary design of precoolers using liquid gas as refrigerants is available from gas supplier such as Liquid Carbonic.

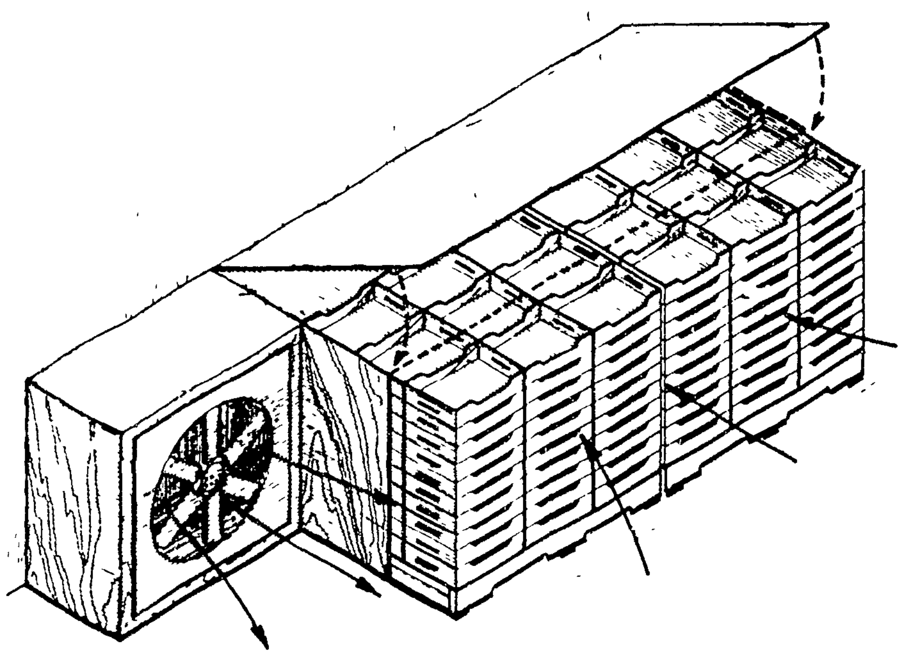

Figure 20. Precooler for small fruits to be added to existing cold room. A corridor is created between the walls of the cold room and a row of crates by closing a flap over the corridor. Air is drawn through the crates into the corridor by a fan located at one end. The air expelled by the fan is cooled by the refrigeration system of the cold room before it is recirculated through the berries (Plan # 60506) (Belzile, 1986).

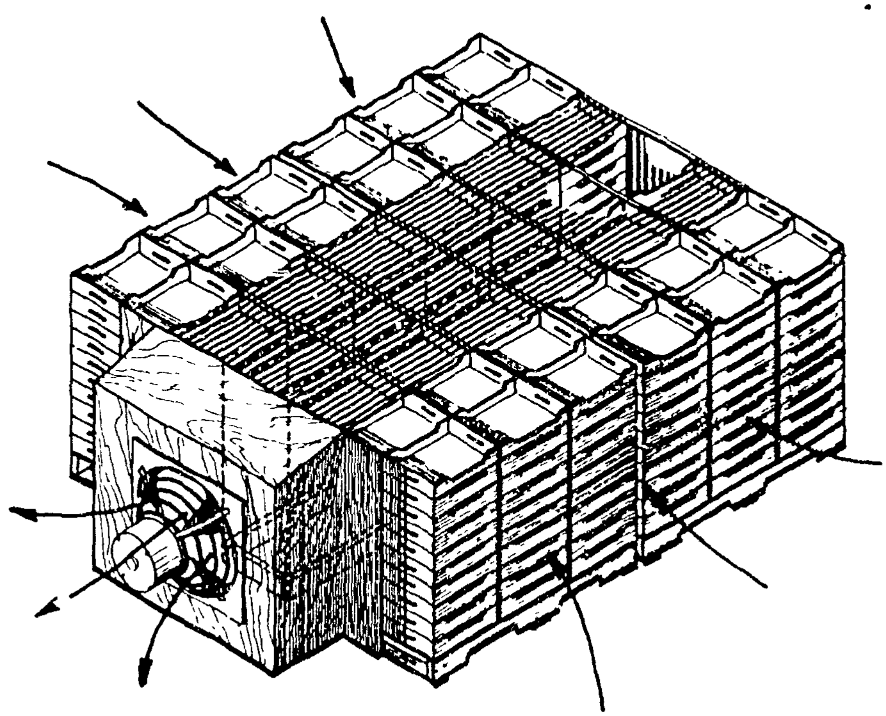

Figure 21. Precooler for small fruits to be added to a cold room. Cold air is drawn from both side of the tunnel for increase capacity. (Plan # 60505) (Belzile, 1986).

Table 16. Comparison of precooling cost per kilogram in a conventional cold room and one using liquid gas as a refri gerant.

Precoolers	Cost				
	Acquisition		Energy[2]	Handling[3]	Total
	Actual	\$/kg[1]	\$/kg	\$/kg	\$/kg
Conventional	\$ 8 500	\$ 0.072	negligible	\$ 0.025	\$ 0.097
Liquid gas	\$ 2 100	\$ 0.018	\$0.16	\$ 0.025	\$ 0.203

1. Cost of acquisition recovered within 5 years. Cost per kg calculated on 117 500 kg (23 500 kg X 5 year).
2. Cost of the liquid gas or the electricity necessary to cool one kilogram of berry.
3. Cost of handling the berries in and out of the precooler.

5.2. Benefits Derived from Precooling

Precooling strawberries is an additional operation in the handling of strawberries that needs additional costs in equipment and manpower. To recover those costs, a significant reduction in spoilage is expected. Precooling will reduce decay after two days by 75% if it is done promptly after harvest and down to a temperature of 5 °C (Tonini, 1983). This means that at delivery at the retailer, the percentage of unmarketable berries would drop from 15% to 4 %.

The economic analysis carried for the proposed example shows that the precooling costs outweigh the benefits derived from the reduction in losses (Table 17). After 5 years, the costs of precooling with the mechanical system would almost breakeven with the revenues. If we consider the precooler is used less than four weeks a year and solely to cool strawberries, precooling is not a good investment. To be profitable, the system would have to be in operation for a longer period of time (for instance by extending harvesting season with a late ripening variety). The costs could be shared by precooling other crops such as tomatoes, raspberries, sweet corn, etc.. Precooling costs could be recovered by obtaining a better price for strawberries .

The example provided shows that precooling is not beyond the means of a good proportion of Québec strawberry growers. The investment required is relatively small and subsidies are available from the Québec Ministry of Agriculture to help cover up to 50% of the initial cost of the building and the equipment.

5.3. Storage in CA.

Precooled strawberries will keep better if they are stored in CA. Storage might be advantageous to producers who want to time their marketing with the large daily and weekly price fluctuations common on the Québec market. Some days (Tuesday and Thursday in particular), producers that can deliver early in the night will get better prices (CAGRIC, 1972). Prices on Monday and Friday nights are usually low because the supply of berries exceeds the demand. Prices are usually high just before or just after a rainfall (CAGRIC, 1972). The price for a crate (4.5 kg) can vary by as much as $ 4.00 within a period of 12 hours.

Table 17. Summary of various costs, benefits and ROI for liquid gas and mechanical precooling.

PRECOOLER TYPE	LIQUID GAS	MECHANICAL
Initial Costs		
Building	$ 2,100.	2,100.
Equipment[1]	---	6,400.
Total	2,100.	8,500.
Annual costs		
Energy[2]	3,760.	20.
Operation[3]	600.	600.
Maintenance	50.	200.
Amortization[4]	420.	1,700.
Interest on loan[5]	189.	770.
Total	5,019.	3,290.
Revenue	3,100.	3,100.
R.O.I.[7]		
No amortization	(33 %)	95 %
With amortization	(38 %)	(6 %)

1. Equipment cost for mechanical refrigeration system (2 tons capacity)
2. Cost of cooling for liquid gas is $ 0.16/kg X 23 500 kg
   for mechanical is $ 1.40/day X 14 days
3. Operation costs is cost of extra handling to stack crates in precooler.
4. Initial cost of building and equipment amortized in 5 years.
5. Interest on loan on building and equipment is 15%. Yearly payment of interest are set equal in the analysis.
6. Precooling reduces losses from 15% to 4%. Revenues are drawn from the sales of 2 585 kg (11% X 23 500 kg) of berries at $ 1.20/kg.
7. R.O.I. is return on investment

$$= \frac{\text{Revenue - costs (with or without amortization)}}{\text{Costs with or without amortization}}$$

A producer who could store his harvest and keep it until he feels the market is ready could stabilize his income. New markets could be found as the harvests from two to three days could be grouped and sold to wholesalers.

Although it involves more care than RA storage, CA storage is not that difficult to achieve. Dry ice or gas tank can be used to create CA. When using gas tanks, the most important point to check is the airtightness of the room or containers in which CA is maintained. When using dry ice, the rate of sublimation has to be matched with the ventilation rate (through leaks or forced ventilation). Sublimation curves for dry ice in bulk and in pellets are available from gas suppliers (Figure 22). From these we find, for instance, that the sublimation rate of dry ice at 5 °C for a cube of 22.7 kg (50 lbs) is about 1 kg/hr for the first 10 hours. Suppose an enclosure of 3 m^3 with 50 % free space and one air change every hour. A 20 % CO_2 concentration can be maintained in the enclosure as long as 0.3 m^3/h of gaseous CO_2 is supplied (see sample calculations in Appendix D). The sublimation of 1 kilogram of dry ice produces about 0.56 m^3 of gaseous CO_2. This means about 0.5 kg/hr of dry ice would have to sublimate in the enclosure to maintain the desired CA. This can be obtained by leaving a block of dry ice of 16 to 20 kg in the enclosure.

Given a cost of \$ 0.50 per kilogram of dry ice, the cost of the gas to maintain the enclosure in CA for 72 hours would be about \$18.00. If 400 crates (4.5 kg) of strawberries are stored in the

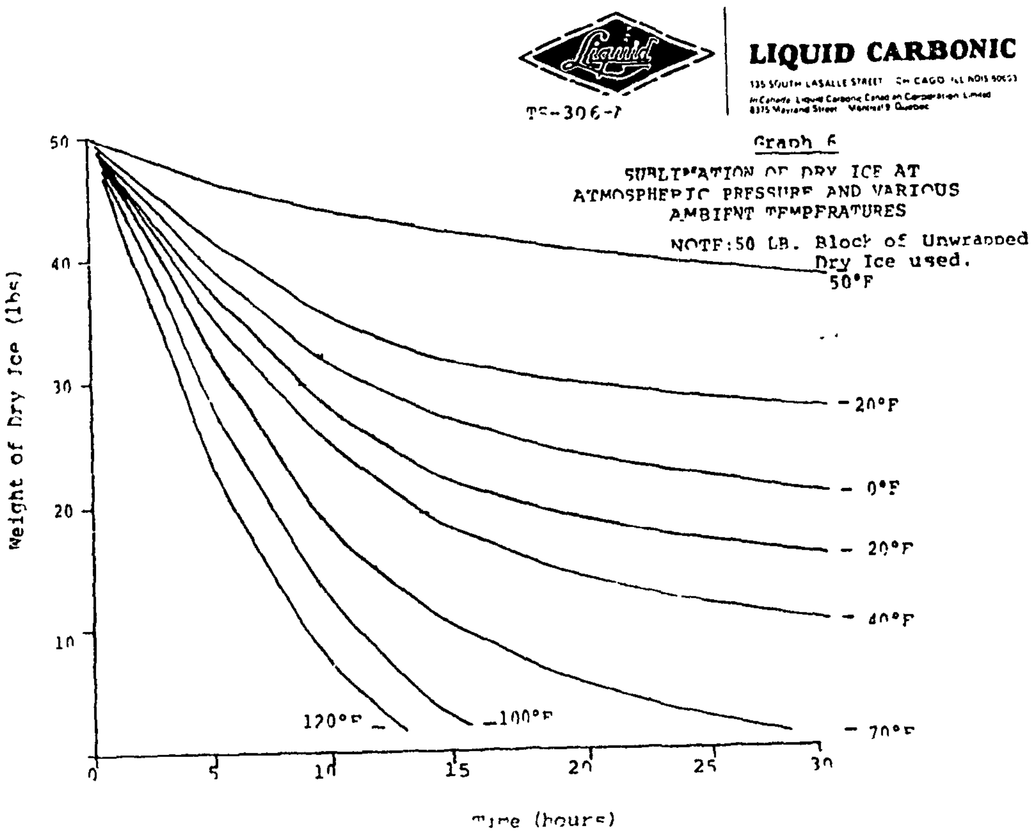

Figure 22. Sublimation rates and amount of dry ice to maintain CA in an enclosure.

enclosure, CA storage would cost only $ 0.05 more per crate than regular RA storage.

Knowing the inhibitory effects of CA on fungi growth, the additional investment required to maintain an enclosure in CA would be more than justified in situations similar to the one presented.

VI. SUMMARY AND CONCLUSIONS

6.1. Summary

This study was carried out to investigate the handling of strawberries in Quebec. The most important parameters influencing quality and shelf life were identified and the harvesting and handling methods followed in Quebec were evaluated. Better harvesting methods, precooling and CA storage would greatly improve strawberry quality. This was demonstrated in a factorial experiment where recommended harvesting and handling methods were followed. Strawberries of the Red Coat variety harvested at the right maturity and precooled shortly after harvest kept for 10 days when stored at 5 °C in CA composed of 16% CO_2, 20% O_2 and 64% N_2. Except for an increase in skin and flesh firmness, storage in CA did not influence the quality parameters. Exposure to high CO_2 concentrations while precooling had no effect on the shelf life or quality of strawberries.

Following CA storage, the residual shelf life of strawberries stored in conditions found in retail stores was evaluated. Strawberries were kept successively at 22 °C and 10 °C for periods of 12 hours. After two days of this regime, 80% of the berries previously stored in CA were still sound compared to 55% of the berries stored in RA. CA storage extended shelf life by inhibiting fungal growth.

The inhibition of fungal growth was demonstrated in an experiment where CA prevented the spread of infection from a decaying strawberry to berries in the same container. CA was effective in preventing the growth of Botrytis cinerea, Rhizopus species, and Alternaria tenuis.

Preliminary estimates indicate precooling and CA storage are economically feasible and would be profitable for growers harvesting more than 5 hectares per season.

6.2. Conclusions

The following conclusions were drawn from the work carried out in this study:

i) precooling is essential to the conservation of strawberries for periods longer than one day.

ii) CA storage composed of 16 +/- 1.5% CO_2, 20 +/- 1% O_2 and 64 +/- 2% N_2 is an effective means of preventing fungal growth in strawberries stored at 5 ^oC and at room tempera ture.

iii) exposure to high CO_2 concentrations for two hours have no effects on strawberry quality.

6.3. Recommendations for further research

The handling of strawberries encompasses many aspects that the present study did not cover fully. The effect of precooling and CA storage on the shelf life of other cultivars popular in Quebec such as Bounty and V star should be evaluated. More work is required to complete the design of a precooler for the small strawberry producers. The procedure to establish and maintain CA in a section of a cold room using dry ice has to be refined. A standard method to handle strawberries from the farm throughout the distribution channels should be developed to prevent spoilage due to bruising and poor storage conditions. With the shortage of manpower, special considerations should be given to the handling of mechanically harvested strawberries and the procedure to integrate precooling and CA storage with actual processing methods followed by jam manufacturers.

LITERATURE CITED

A.O.A.C. 1980. Association of Official Agricultural Chemists. Official methods of analysis. Washington. D.C.

Barritt, B.H. 1980. Resistance of strawberry clones to Botrytis fruit rot. J. Amer. Soch. Hort. Sci. 105:160-164.

Belzile, Gilbert, 1986. Personal communication.

Berthelot, M. 1984. Coût de production de la fraise. Service de l'économie de la production. Direction des Etudes économiques, MAPAQ, 40 p. Québec.

Bhatt, D.D. and E.K. Vaughan. 1962. Preliminary investigations on biological control of gray mold (Botrytis cinerea) of strawberries in Oregon. Phytopathology 53:217-220.

Borecka, H. and D.F. Millikan. 1981. Influence of storage conditions upon the development of postharvest gray mold rot of strawberries. Phytoprotection 62:1:11-16.

Bourne, M.C. 1982. Effect of temperature on firmness of raw fruits and vegetables. J. Food Sc. 47:440-444.

Brooks, C., E.V. Miller, C.O. Bratley, J.S. Cooley, P.V. Mook and H.B. Johnson. 1932. Effect of solid and gaseous carbon dioxide upon transit diseases of certain fruits and vegetables. USDA Bull. 318, 60 pp.

Browne K.M., J.D. Geeson and C. Dennis. 1984. The effects of harvest date and CO_2 enriched storage atmospheres on the storage and shelf life of strawberries. J. Hort. Sci. 59:2: 197-204.

Burg, S.P. 1975. Hypobaric storage and transportation of fresh fruits and vegetables. pp. 172-188. In N.F. Haard and D.K. Salunkhe (eds), Symposium: Postharvest Biology and Handling of Fruits and Vegetables. AVI, Westport, Conn.

Buth, D. and E. McKibbon. 1984. Strawberry production costs in Ontario. Economics Information Report no. 84-03. Economics Branch, OMAF.

CAGRIC. 1972. Ecude sur la mise en marché des fraises au Québec. Montréal. 137 p.

Chalutz, F. E. Maxii and N.F. Sommer. 1965. Interaction of gamma irradiation and controlled atmospheres on Botrytis cinerea rot of strawberry fruit. Proc. Am. Soc. Hort. Sci. 88:365-371.

Childers, F.N. 1980. The strawberry: cultivars to marketing. Proceedings of the Natl. Strawberry Conf., St Louis, Mis., 514 p.

Cohen, E. and C. Dennis. 1975. Effect of fungicides on the mycelial growth of soft fruit spoilage fungi. Annals of Applied Biol. 80:237-242.

Couey, H.M., M.N. Follstad and M. Vota. 1966. Low oxygen atmospheres for control of postharvest decay of fresh strawberries. Phytopath. 56:1213-1338.

Couey, H.M. and J.M. Wells. 1970. Low oxygen and high carbon dioxide atmospheres to control postharvest decay of strawberries. Phytopath. 60:47-49.

Dale, A. 1985. Developments with solid bed culture and mechanical harvesting and processing. in Perspectives de développement. Symposium sur la culture de la fraise. Université Laval, 14-15 nov. 1985. CPVQ Agdex 230/20.

Dennis, C. and J. Mountford. 1975. The fungal flora of soft fruits in relation to storage and spoilage. Ann. Appl. Biol. 79:141-147.

Doren, van A., M.B. Hoffman and R.M. Smock. 1941. Carbon dioxide treatment of strawberries and cherries in transit and storage. Proc. Am. Soc. Hort. Sci. 38:231-238.

Draper N. R. and H. Smith. 1981. Applied regression analysis. 2nd ed. John Wiley & Sons, N.Y., 437 p.

Dufour, J.C. 1985. Des contenants recouverts pour la mise en marché des fraises au Québec: est ce désire et désirable ? in Perspectives de développement, Symposium sur la culture de la fraise. Université Laval, 14-15 nov. 1985 CPVQ Agdex 230/20.

El Goorani, M.A. and N.F. Sommer. 1979. Suppression of postharvest plant pathogenic fungi by CO. Phytopathology 69:834-838.

El Goorani, M.A. and N.F. Sommer. 1981. Effects of modified atmospheres on postharvest pathogens of fruits and vegetables. Agric. Rev. 3:412-462.

El Kazzaz, M.K., N.F. Sommer anf R.J. Fortlage. 1983. Effect of different atmospheres on postharvest decay and quality of fresh strawberries. Phytopath. 73:282-285.

Freeman, J.A. and H.S. Pépin. 1977. Control of postharvest rot of strawberries by field sprays. Can. J. Plant. Sci. 57:75-80.

Fulton, S.H. 1907. The cold storage of small fruits. USDA Bur. Plant Indus. Bull. 108, 28 p.

Gerhart, R.A. 1930. Respiration in strawberry fruits. Bot. Gaz. 89:20-29.

Girard, R. 1985. Fédération des producteurs de fraises et framboises du Québec. Personal communication.

Guillou, R. 1960. Coolers for fruits and vegetables. U.C. Agric. Exp. Sta. Bull. 773.

Haller, M.H., P.L. Harding, J.M. Lutz and D.H. Rose. 1933. The respiration of some fruits in relation to temperature. Proc. Am. Soc. Hort. Sci. 29: 583-589.

Harris, C.M. and J.M. Harvey. 1973. Quality and decay of California strawberries stored in CO_2 enriched atmospheres. Plant Dis. Reptr. 57:1:44-46.

Harris, C.M., F.M. Porter and J.M. Harvey. 1969. Market quality and precooling rates of strawberries packed in various containers. U.-S.D.A. Marketing Res. Rept. no. 851.

Hart, S.A. 1964. Handling strawberries for fresh market. Calif. Agric. Exp. Stn. Circular 527, 16 p.

Harvey, J.M., H.M. Couey, C.M. Harris and F.M. Porter. 1965. Air transport of California strawberries: factors affecting market quality in summer shipments. U.S.D.A. Mkgt. Res. Rept. 751, 17 p.

Harvey, J.M., C.M. Harris, W.J. Tutjen and T. Serio. 1980. Quality maintenance in truch shipments of California strawberries. Adv. in Agric. Tech. U.S.D.A. Publ. . AAT-W12.

Ingle, M. 1970. Studies on the postharvest physiology and handling of strawberries. Bull. W. Va. Univ. Agric. Exp. Stn. 596T.

Institut québécois d'opinion publique. 1984. Etude de marché sur les fraises et framboises du Québec. IQOP INC.

Janes H.W., Chee Kok Chin and Chaim Frenkel. 1978. Respiratory upsurge in blueberries and strawberries as influenced by ethylene and acetaldehyde. Bot. Gaz. 139:1:50-52.

Jarvis, W.R. 1977. Botryotinia and Botrytis species: taxonomy, physiology and parthogenecity. Can Dept. Agr. Res. Br. Monogr. 15. 195p.

Khalid, A.S. and V.W.L. Jordan. 1976. The effect of temperatures and humidity on Rhizopus soft rot of strawberries. Sudan J. FD. Sci. Technol. 8: 61-67.

Kidd, F. and C. West. 1919. Food Invest. Bd. Ann. Rept. 14: 17-18.

Krahn T.R. and D.E. Darby. 1971. The Filacell system for refrigerated vegetable storage. Can. Soc. Hort. Sci. ann. meeting. 9pp.

Lafleur, K. 1985. Le recours à la palettisation comme mode de distribution et de commercialisation au détail de la fraise au Québec. These de maitrise non publiee presentée à l'Ecole des gradués, Université Laval.

Lange, E., W. Plocharski and W. Lenortowicz. 1978. Strawberries: quality of fruits, their storage life and suitability for processing. Part 1. The influence of control atmospheres and low pressure on the storage of strawberry fruits. Fruit Sc. Rept. 5:2: 39-46.

Mason D.T. and W.R. Jarvis. 1970. Post harvestt ripening of strawberries. Hort. Res. 10: 125-132.

Maxie, E.C., N.F. Sommer, and F.G. Mitchell. 1971. Infeasibility of irradiating fresh fruits and vegetables. HortScience 6:3:202-204.

Mitchell, F.G., E.C. Maxie and A.S. Greathead. 1964. Handling strawberries for the fresh market. Calif. Agric. Exp. Stn. Circ. 527, 18 p.

Monma,S and S. Kamimura. 1978. Varietal differences in shelflife of strawberry fruits and its controlling factors. Hort. Abst. 49:4874.

Money, R.W. and W.A. Christian. 1950. Analytical data of some common fruits. J. Sci. Food & Agr. 1:8-12.

Morris, J.R., S.E. Spaid, D.L. Cawthon, A.A. Kattan and G.S. Nelson. 1979. Strawberry clonal fruit yield and quality response to hand picking prior to once over harvest. J. Amer. Soc. Hort. Sci. 104: 864-867.

Morris, J.R. 1980. Strawberry mechanization: a total system approach. in The Strawberry: cultivars to marketing. Proceedings of the Natl. Strawberry Conf., St Louis, Mis. 514 p.

Morris, J.R. 1983. Influence of mechanical harvesting on quality of small fruits and grapes. HortSc. 18:4:412-417.

Neal, G.E. 1965. Changes occurring in the cell walls of strawberries during ripening. J.Sci. Food. & Agr. 16: 604-611.

Oliver, M. 1967. Ascorbic acid occurrence in foods in Sebrell W.H. and R.S. Harris (eds.). The vitamins, vol. 1. ed.7, pp. 359367.

Ourecky, D.K. and M.C. Bourne. 1968. Measurement of strawberry texture with an Instron machine. Proc. Am. Soc. Hort. Sci. 93:317-325.

Overholser, E.L., M.B. Hardy and H.D. Locklin. 1931. Respiration of strawberries. Plant Phys. 6: 549.

Plocharski, W.W., E. Lange and W . Lenartowicz. 1978. Strawberries: quality of fruits, their storage life and suitability for processing: Part II. Changes in strawberry quality in relation to storage conditions. Fruit Sc. Rep. 5:2:47-55.

Plocharski, W.W. 1982. Strawberries: quality of fruits, their storage life and suitability for processing. Part III. Firmness and pectic substances changes in strawberries stored under normal and controlled atmosphere conditions. Fruit Sc. Rep. 9:3:111-122.

Raghavan, G.S V. and Y. Gariépy. 1984. Structure and instrumentation aspects of storage systems. Actae Horticulturae 157:5-30.

Rohrbach R.P., R. Ferrell, E.O. Beasley and J.R. Fowler. 1984. Precooling Blueberries and Muscadine Grapes with liquid carbon dioxide. Trans. of the ASAE:27(6):1950-1955.

Salunkhe, D.K. and B.B. Desai. 1984. Postharvest biotechnology of fruits. Vol. 1. C.R.C. Press, U.S.A.

Skrede, G. 1980. Strawberry varieties for industrial jam production. J. Sci. Food Agric. 31:670-676.

Smith, W.H. 1938. The gas storage of strawberries. Grt. Brit. Dept. Sci. Ind. Res. Rept. Food Invest. Bd. 1937:35:165.

Smith, W.L. Jr and J.T. Worthington III. 1965. Reduction of postharvest decay of strawberries with chemical and heat treatments. Plant Dis. Rep. 643. 24 p.

Sommer, N.F. and D.A. Luvisi. 1960. Choosing the right package for fresh fruit. Package engineering. 5:12:37-43.

Spayd, S.E. and J.R. Morris. 1981. Physical and chemical characteristics of puree from once-over harvested strawberries. J. Amer. Soc. Hort. Sci. 106:105-109.

Sweeney J.P., V.J. Chapman and P.A. Hepner. 1970. Sugar, acid and flavor in fresh fruits. J. Am. Dietetic Ass. 57:432-435.

Thornton, C.T. 1933. Carbon dioxide storage. Part III. The influence of carbon dioxide on the oxygen uptake by fruits and vegetables. Contr. Boyce Thompson Inst. 5:371-402.

Tonini, G. 1983. New precooling and transport techniques for limiting postharvest diseases of strawberries. Ortofloricoltura 45:11:7-13.

Tronsmo, A. and C. Dennis. 1977. The use of Trichoderma species to control strawberry fruit rots. Neth. J. Pl. Path. 83: Suppl. 1: 449-455.

Wells, J.M. 1970. Modified atmosphere, chemical and heat treatments to control postharvest decay of California strawberries. Plant Dis. Rept. 54: 431-434.

Whiting, G.C. 1958. The non volatile organic acids of some berry fruits. J. Sci. Food.& Agr. 9:4:244-248.

Woodward, J.R. 1972. Physical and chemical changes in developing strawberry fruits. J. Sci. Fd. Agric. 23:465-473.

Woodward, J.R. and A. J. Topping. 1972. The influence of controlled atmosphere on the respiration rates and storage behaviour of strawberry fruits. J. Hort. Sci. 47:547-553.

APPENDICES

A. Cost comparison between hand harvesting and machine harvesting.

B. Isolation and identification of fungi present in the field.

C. Results of the ANOVA and of Duncan's new multiple range tests on factor effects and treatment combinations.

D. Sample calculations to determine the amount of dry ice necessary to maintain CA in an enclosure.

Appendix A. Costs comparison between hand harvesting and machine harvesting

According to a study made by Institut québécois d'opinion publique (1984), 40% of the consumers get their fresh strawberries directly from the growers having pick your own operations, 28% buys them at public markets and 32 % buy them from a retailer such as grocery stores.

Depending on the management of harvesting, the harvesting costs (labor, machinery and container costs) will vary. For commercial harvesting more than 1 235 hours of labor per hectare are required to pick an average of 7 475 kg/ha (Buth and McKibbon, 1984). Labor is the major harvesting cost at $ 3786 per hectare, containers account for $ 1 995 per hectare and machinery for $ 133. Total cost per hectare is $ 5 873. Harvesting costs per kilogram are nearly 79 cents with labor accounting for 51 cents, containers for 26 cents and machinery for 2 cents per kilogram.

For pick your own operations, labor hours are less than 198 hours per hectare which is much lower than for commercial harvesting. Total harvesting cost is lowered to $ 617.00 per hectare to pick an average of 6 707 kg/ha. Labor costs 14.3 cents/kg, advertising 5.1 cents/kg and machinery 3.3 cents/kg, for a total of 22.7 cents per quart. The difference in harvesting costs between commercial picking and PYO is 56.3 cents per quart.

Mechanical harvesting is generally used to pick strawberries to be sold to processors. Self propelled and tractor drawn mechanical harvesters are available on the market. In 1984, a self propelled unit capable of harvesting 0.4 ha a day sold for $82,000.00 while a tractor mounted unit of similar capacity sold for $ 30,000.00 to $ 50,000.00 . For mechanical harvesting, the labor required to pick an average of 13,517 kg/ha was estimated at a 100 hours (Dale, 1985). The total harvesting cost per kilogram was 31.4 cents and storage bin rental 1.1 cents. Under Canadian short harvesting period, the mechanical harvester tested by Dale (1985) could harvest at least 4 hectares per season.

Appendix B. Isolation and identification of fungi present in the field.

The presence of major pathogenic fungi on the strawberries harvested for the experiments was verified. The presence of fungi was verified by visual inspection and by incubating selected samples of strawberry tissues and isolating the molds present. The method followed for the isolation and culture of fungi was derived from the one suggested by Dennis and Mountford (1975) and Jarvis (1977).

After incubating the cultures for 5 days at 20 °C, pictures of the colonies were taken. Three fungi were predominant in the samples gathered from both harvests: Botrytis cinerea , Rhizopus species, and Alternaria tenuis (Figure B.1, Figure B.2, Figure B.3).

Figure B.1. Botrytis cinerea . (Note: white dots are a result of poor processing during film development)

Figure B.2. Rhizopus stolonifer.

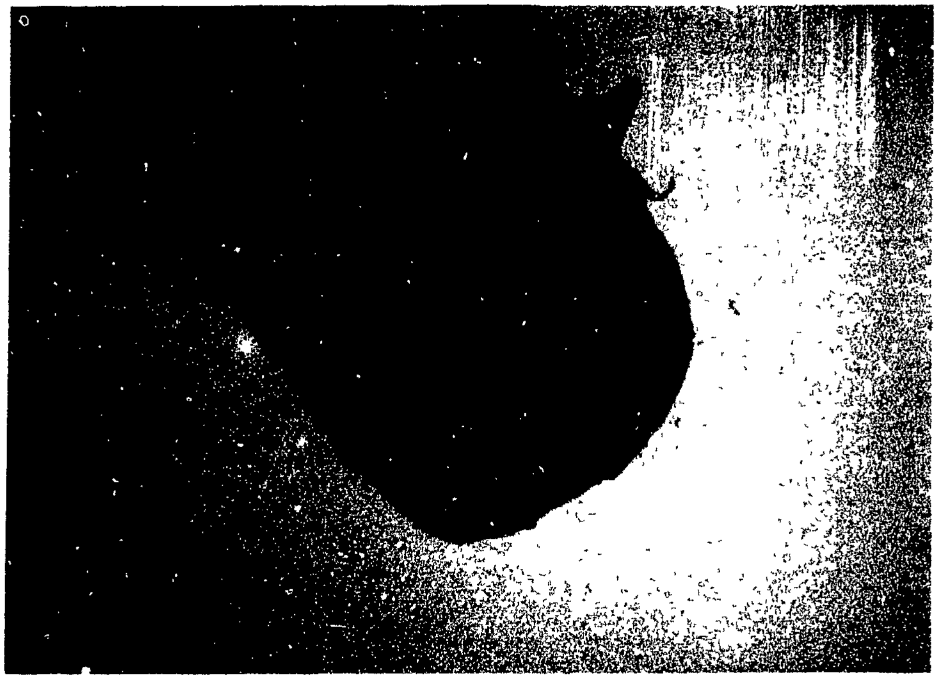

Figure B.3. Alternaria tenuis. (Note: white spots are a result of poor processing during film development).

Appendix C. Results of the ANOVA and of Tukey's studentized range tests on factor effects and treatment combinations.

```
1         SAS(R) LOG    OS SAS 5 16            MVS/XA JOB AE38      STEP SAS                    14 13 THURSDAY, JULY 21, 1988
NOTE   COPYRIGHT (C) 1984,1986 SAS INSTITUTE INC , CARY, N C   27511, U S A
NOTE   THE JOB AE38 HAS BEEN RUN UNDER RELEASE 5 16 OF SAS AT MCGILL UNIVERSITY COMPUTING CENTRE (01192001)
NOTE   CPUID   VERSION = 82  SERIAL = 000016  MODEL = 0580
NOTE   SAS OPTIONS SPECIFIED ARE
        SORT=4 NODYNALLOC

1          DATA EXP1, INPUT HA LE  YEAR  DAY  PICK WEIGHT PEAK1 PEAK2
2                      AVGPK   PH ACID  SS  LOSS MOIST  GOOD STOR $
3          61-62 PRE $ 63-64,
4          TGOOD=ARSIN(SQRT(GOOD/100 0)),
5          TMOIST=ARSIN(SQRT(MOIST/100 0)),
6          TLOSS=ARSIN(SQRT(LOSS/100 0)),
7          TACID=ARSIN(SQRT(ACID/100 0)),
8          TSS=ARSIN(SQRT(SS/100 0)),
9          NEWT1=PEAK1* 00981,
10         NEWT2=PEAK2* 00981,
11         CARDS,

NOTE   SAS WENT TO A NEW LINE WHEN INPUT STATEMENT
       REACHED PAST THE END OF A LINE
NOTE   DATA SET WORK EXP1 HAS 48 OBSERVATIONS AND 24 VARIABLES  254 OBS/TRK
NOTE   THE DATA STATEMENT USED 0 11 SECONDS AND 108K

71         PROC SORT, BY YEAR HA STOR PRE,

NOTE   4 CYLINDERS DYNAMICALLY ALLOCATED ON SYSDA FOR EACH OF 3 SORT WORK DATA SETS
NOTE   DATA SET WORK EXP1 HAS 48 OBSERVATIONS AND 24 VARIABLES  254 OBS/TRK
NOTE   THE PROCEDURE SORT USED 0 19 SECONDS AND 416K

72         PROC PRINT, VAR YEAR HA STOR PRE GOOD LOSS MOIST PH ACID WEIGHT
73                     SS NEWT1 NEWT2,
NOTE   THE PROCEDURE PRINT USED 0 12 SECONDS AND 556K AND PRINTED PAGE 1

74         PROC PRINT, VAR YEAR HA STOR PRE TGOOD TLOSS TMOIST TACID TSS,
NOTE   THE PROCEDURE PRINT USED 0 11 SECONDS AND 556K AND PRINTED PAGE 2

75         DATA Q1, SET EXP1,
76         IF YEAR EQ 2 THEN DELETE,

NOTE   DATA SET WORK Q1 HAS 32 OBSERVATIONS AND 24 VARIABLES  254 OBS/TRK
NOTE   THE DATA STATEMENT USED 0 08 SECONDS AND 412K

77         PROC GLM, CLASSES STOR PRE HA, MODEL TGOOD TLOSS TMOIST PH TACID
78         WEIGHT TSS NEWT1 NEWT2 =STOR PRE HA STOR*HA STOR*PRE PRE*HA STOR*PRE*HA,
79         MEANS STOR PRE  HA / TUKEY,
80         TITLE YEAR 1 BERRIES - FACTORIAL ANALYSIS,
```

113


```
WARNING 620  OBSOLETE FORM OF STATEMENT OR TEXT82 OPTION INCORRECT

NOTE  THE PROCEDURE GLM USED 7 47 SECONDS AND 784K AND PRINTED PAGES 3 TO 39

81          DATA Q2, SET EXP1,
82          IF PPE='CO' THEN DELETE,

NOTE  DATA SET WORK Q2 HAS 32 OBSERVATIONS AND 24 VARIABLES  254 OBS/TRK
NOTE  THE DATA STATEMENT USED 0 08 SECONDS AND 412K

83          PROC GLM, CLASSES YEAR HA STOR,
84          MODEL TGOOD LOSS TMOIST PH TACID WEIGHT TSS NEWT1 NEWT2=YEAR HA
85                STOR YEAR*HA YEAR*STOR STOR*HA YEAR*STOR*HA,
86          MEANS STOR YEAR HA / TUKEY,
87          TITLE YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED,

WARNING 620  OBSOLETE FORM OF STATEMENT OR TEXT82 OPTION INCORRECT

NOTE  THE PROCEDURE GLM USED 7 47 SECONDS AND 784K AND PRINTED PAGES 40 TO 76
NOTE  SAS USED 784K MEMORY

NOTE  SAS INSTITUTE INC
      SAS CIRCLE
      PO BOX 8000
      CARY, N C  27511-8000
```

SAS   14 13 THURSDAY, JULY 21, 1988   1

OBS	YEAR	HA	STOR	PRE	GOOD	LOSS	MOIST	PH	ACID	WEIGHT	SS	NEWT1	NFWT2
1	1	1	CA	CO	79	1 5	88 9	3 50	0 98	16 2	9 60	4 34583	7 48503
2	1	1	CA	CO	71	1 6	89 0	3 58	0 98	17 0	9 50	4 03191	6 51384
3	1	1	CA	CO	87	1 2	88 8	3 53	1 09	14 6	11 00	4 26735	6 35688
4	1	1	CA	CO	75	1 2	89 4	3 45	1 05	18 0	9 50	4 69899	8 58375
5	1	1	CA	OO	87	1 5	89 5	3 46	1 04	17 9	8 30	4 26735	6 21954
6	1	1	CA	OO	86	1 8	88 1	3 54	1 00	18 1	10 50	4 27716	7 64197
7	1	1	CA	OO	93	2 1	89 7	3 54	0 96	15 5	10 00	3 96324	6 70624
8	1	1	CA	OO	81	1 3	89 5	3 50	0 98	19 5	10 00	3 76704	5 11101
9	1	1	RA	CO	50	2 6	90 5	3 43	1 05	18 3	9 80	3 07053	4 44393
10	1	1	RA	CO	63	2 3	89 8	3 52	0 92	17 3	10 20	2 70756	4 88538
11	1	1	RA	CO	67	2 8	88 6	3 45	1 10	17 3	8 90	2 94300	5 09139
12	1	1	RA	CO	72	2 5	91 0	3 47	0 97	16 4	10 00	2 82528	5 33664
13	1	1	RA	OO	53	2 2	89 2	3 52	0 84	17 8	10 20	3 94362	5 34645
14	1	1	RA	OO	43	2 2	89 6	3 58	0 80	16 8	9 20	2 96262	4 79709
15	1	1	RA	OO	50	3 6	88 7	3 61	0 84	15 6	9 20	3 50217	5 33664
16	1	1	RA	OO	47	2 2	89 2	3 52	0 86	16 4	9 80	4 46355	6 14106
17	1	2	CA	CO	64	0 7	89 7	3 45	0 78	13 2	9 61	3 66894	5 15025
18	1	2	CA	CO	89	0 6	89 1	3 47	0 91	13 2	8 59	3 78666	7 10244
19	1	2	CA	CO	84	1 1	88 3	3 52	0 91	10 1	9 79	3 85533	5 01291
20	1	2	CA	CO	61	0 8	87 6	3 44	0 91	13 2	10 22	3 53160	6 07239
21	1	2	CA	OO	86	0 6	88 4	3 42	0 75	12 0	8 28	3 15882	4 03191
22	1	2	CA	OO	89	0 9	87 2	3 40	0 99	11 1	9 51	3 81609	5 02272
23	1	2	CA	OO	71	0 6	89 1	3 48	0 81	12 4	8 78	3 54141	4 99329
24	1	2	CA	OO	73	1 5	88 0	3 54	1 46	14 3	9 97	3 75723	5 14044
25	1	2	RA	CO	48	0 3	88 1	3 40	1 35	11 9	8 65	3 39426	6 41574
26	1	2	RA	CO	52	0 5	90 0	3 61	0 98	13 5	8 67	3 57084	6 01353
27	1	2	RA	CO	58	4 7	89 5	3 53	0 85	13 0	9 83	3 24711	4 73823
28	1	2	RA	CO	23	2 5	88 8	3 42	1 09	12 6	10 03	3 85533	7 10244
29	1	2	RA	OO	66	0 4	87 8	3 39	0 91	10 2	8 72	2 83509	4 70880
30	1	2	RA	OO	70	1 0	88 3	3 48	0 87	11 5	8 80	2 30535	4 57146
31	1	2	RA	OO	72	0 8	88 7	3 42	0 89	10 7	9 45	2 24649	4 70880
32	1	2	RA	OO	51	1 1	89 2	3 44	0 98	9 1	10 02	2 65851	4 13982
33	2	1	CA	OO	78	1 4	89 1	3 47	1 05	13 9	8 30	4 21830	5 66037
34	2	1	CA	OO	67	1 5	89 2	3 59	0 91	13 9	10 10	3 22749	6 33726
35	2	1	CA	OO	79	1 3	90 2	3 60	0 90	14 5	9 70	3 13920	5 66037
36	2	1	CA	OO	79	1 5	89 9	3 53	0 97	12 2	10 00	2 85471	5 29740
37	2	1	RA	OO	38	1 9	90 3	3 64	0 93	14 8	9 30	4 40469	5 54265
38	2	1	RA	OO	59	1 7	88 8	3 57	0 75	16 0	9 70	3 52179	5 43474
39	2	1	RA	OO	71	1 6	88 7	3 44	1 20	13 9	10 20	2 97243	4 79709
40	2	1	RA	OO	63	1 5	89 0	3 41	1 05	11 8	10 20	2 78604	4 37526
41	2	2	CA	OO	85	1 6	89 6	3 43	0 89	8 6	9 51	2 83509	3 19806
42	2	2	CA	OO	75	2 0	88 9	3 55	0 94	8 6	9 11	3 93381	4 37526
43	2	2	CA	OO	63	1 9	90 2	3 48	0 98	10 2	8 48	2 97243	4 81671
44	2	2	CA	OO	81	1 1	89 4	3 40	0 93	11 4	9 70	3 61008	5 03253
45	2	2	RA	OO	56	1 8	89 8	3 57	1 18	9 8	10 93	3 76704	4 70880
46	2	2	RA	OO	43	0 7	88 7	3 46	1 21	9 1	10 81	3 42369	4 03191
47	2	2	RA	OO	64	0 6	89 3	3 42	1 24	10 8	11 45	3 80628	5 67999
48	2	2	RA	OO	39	0 6	89 2	3 53	1 01	8 4	10 93	3 37464	3 58065

OBS	YEAR	HA	STOR	PRE	TGOOD	TLOSS	TMOIST	TACID	TSS
1	1	1	CA	CO	1 09476	0 122783	1 23114	0 099157	0 315023
2	1	1	CA	CO	1 00212	0 126831	1 23273	0 099157	0 313322
3	1	1	CA	CO	1 20193	0 109765	1 22955	0 104594	0 338065
4	1	1	CA	CO	1 04720	0 109765	1 23918	0 102650	0 313322
5	1	1	CA	OO	1 20193	0 122783	1 24080	0 102158	0 292239
6	1	1	CA	OO	1 18730	0 134570	1 21860	0 100167	0 329994
7	1	1	CA	OO	1 30303	0 145426	1 24408	0 098137	0 321751
8	1	1	CA	OO	1 11977	0 114266	1 24080	0 099157	0 321751
9	1	1	RA	CO	0 78540	0 161952	1 25747	0 102650	0 318402
10	1	1	RA	CO	0 91691	0 152245	1 24573	0 096064	0 325069
11	1	1	RA	CO	0 95886	0 168123	1 22639	0 105074	0 302941
12	1	1	RA	CO	1 01320	0 158780	1 26610	0 098649	0 321751
13	1	1	RA	OO	0 81542	0 148873	1 23594	0 091780	0 325069
14	1	1	RA	OO	0 71517	0 148873	1 24244	0 089562	0 308170
15	1	1	RA	OO	0 78540	0 190894	1 22797	0 091780	0 308170
16	1	1	RA	OO	0 75538	0 148873	1 23594	0 092870	0 318402
17	1	2	CA	CO	0 92730	0 083764	1 24408	0 088433	0 315193
18	1	2	CA	CO	1 23273	0 077537	1 23433	0 095539	0 297454
19	1	2	CA	CO	1 15928	0 105074	1 22170	0 095539	0 318234
20	1	2	CA	CO	0 89631	0 089562	1 21094	0 095539	0 325400
21	1	2	CA	OO	1 18730	0 077537	1 22325	0 086711	0 291877
22	1	2	CA	OO	1 23273	0 095011	1 23594	0 099664	0 313493
23	1	2	CA	OO	1 00212	0 077537	1 23433	0 090122	0 300828
24	1	2	CA	OO	1 02440	0 122783	1 21705	0 121126	0 321250
25	1	2	RA	CO	0 76539	0 054800	1 21860	0 116453	0 298523
26	1	2	RA	CO	0 80540	0 070770	1 24905	0 099157	0 298879
27	1	2	RA	CO	0 86574	0 218530	1 24080	0 092327	0 318906
28	1	2	RA	CO	0 50018	0 158780	1 22955	0 104594	0 322250
29	1	2	RA	OO	0 94826	0 063288	1 21399	0 095539	0 299766
30	1	2	RA	OO	0 99116	0 100167	1 22170	0 093410	0 301181
31	1	2	RA	OO	1 01320	0 089562	1 22797	0 094480	0 312468
32	1	2	RA	OO	0 79540	0 105074	1 23594	0 099157	0 322084
33	2	1	CA	OO	1 08259	0 118599	1 23433	0 102650	0 292239
34	2	1	CA	OO	0 95886	0 122783	1 23594	0 095539	0 323414
35	2	1	CA	OO	1 09476	0 114266	1 25239	0 095011	0 316717
36	2	1	CA	OO	1 09476	0 122783	1 24738	0 098649	0 321751
37	2	1	RA	OO	0 66422	0 138281	1 25408	0 096587	0 309895
38	2	1	RA	OO	0 87589	0 130756	1 22955	0 086711	0 316717
39	2	1	RA	OO	1 00212	0 126831	1 22797	0 109765	0 325069
40	2	1	RA	OO	0 91691	0 122783	1 23273	0 102650	0 325069
41	2	2	CA	OO	1 17310	0 126831	1 24244	0 094480	0 313493
42	2	2	CA	OO	1 04720	0 141897	1 23114	0 097106	0 306609
43	2	2	CA	OO	0 91691	0 138281	1 25239	0 099157	0 295486
44	2	2	CA	OO	1 11977	0 105074	1 23918	0 096587	0 316717
45	2	2	RA	OO	0 84554	0 134570	1 24573	0 108843	0 336945
46	2	2	RA	OO	0 71517	0 083764	1 22797	0 110223	0 335017
47	2	2	RA	OO	0 92730	0 077537	1 23755	0 111587	0 345193
48	2	2	RA	OO	0 67449	0 077537	1 23594	0 100669	0 336945

YEAR 1 BERRIES - FACTORIAL ANALYSIS 14 13 THURSDAY, JULY 21, 1988 4

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE TGOOD

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	7	0 77932560	0 11133223	8 79	0 0001	0 719364	11 5250
ERROR	24	0 30402802	0 01266783		ROOT MSE		TGOOD MEAN
CORRECTED TOTAL	31	1 08335362			0 11255147		0 97658332

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
STOR	1	0 60218421	47 54	0 0001	1	0 60218421	47 54	0 0001
PRE	1	0 02560888	2 02	0 1679	1	0 02560888	2 02	0 1679
HA	1	0 00969109	0 77	0 3904	1	0 00969109	0 77	0 3904
STOR*HA	1	0 00591064	0 47	0 5011	1	0 00591064	0 47	0 5011
STOR*PRE	1	0 00746214	0 59	0 4503	1	0 00746214	0 59	0 4503
PRE*HA	1	0 04345432	3 43	0 0764	1	0 04345432	3 43	0 0764
STOR*PRE*HA	1	0 08501432	6 71	0 0160	1	0 08501432	6 71	0 0160

YEAR 1 BERRIES - FACTORIAL ANALYSIS 14 13 THURSDAY, JULY 21, 1988 5

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE TLOSS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	7	0 02362028	0 00337433	3 55	0 0093	0 508484	25 6059
ERROR	24	0 02283207	0 00095134		ROOT MSE		TLOSS MEAN
CORRECTED TOTAL	31	0 04645235			0 03084374		0 12045561

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
STOR	1	0 00563368	5 92	0 0228	1	0 00563368	5 92	0 0228
PRE	1	0 00021810	0 23	0 6364	1	0 00021810	0 23	0 6364
HA	1	0 01423929	14 97	0 0007	1	0 01423929	14 97	0 0007
STOR*HA	1	0 00080262	0 84	0 3675	1	0 00080262	0 84	0 3675
STOR*PRE	1	0 00142053	1 49	0 2336	1	0 00142053	1 49	0 2336
PRE*HA	1	0 00092635	0 97	0 3336	1	0 00092635	0 97	0 3336
STOR*PRE*HA	1	0 00037971	0 40	0 5335	1	0 00037971	0 40	0 5335

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE TMOIST

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	7	0 00156425	0 00022346	1 72	0 1523	0 333746	0 9247
ERROR	24	0 00312271	0 00013011		ROOT MSE		TMOIST MEAN
CORRECTED TOTAL	31	0 00468697			0 01140671		1 23356437

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
STOR	1	0 00018555	1 43	0 2441	1	0 00018555	1 43	0 2441
PRE	1	0 00020298	1 56	0 2237	1	0 00020298	1 56	0 2237
HA	1	0 00075692	5 82	0 0239	1	0 00075692	5 82	0 0239
STOR*HA	1	0 00006372	0 49	0 4908	1	0 00006372	0 49	0 4908
STOR*PRE	1	0 00033176	2 55	0 1234	1	0 00033176	2 55	0 1234
PRE*HA	1	0 00000025	0 00	0 9651	1	0 00000025	0 00	0 9651
STOR*PRE*HA	1	0 00002307	0 18	0 6775	1	0 00002307	0 18	0 6775

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE. PH

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	7	0 04262188	0 00608884	2 00	0 0967	0 368871	1 5804
ERROR	24	0 07292500	0 00303854		ROOT MSE		PH MEAN
CORRECTED TOTAL	31	0 11554687			0 05512297		3 48781250

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
STOR	1	0 00002813	0 01	0 9242	1	0 00002813	0 01	0 9242
PRE	1	0 00015312	0 05	0 8243	1	0 00015312	0 05	0 8243
HA	1	0 01950313	6 42	0 0182	1	0 01950313	6 42	0 0182
STOR*HA	1	0 00002812	0 01	0 9242	1	0 00002812	0 01	0 9242
STOR*PRE	1	0 00112813	0 37	0 5480	1	0 00112813	0 37	0 5480
PRE*HA	1	0 01162812	3 83	0 0622	1	0 01162812	3 83	0 0622
STOR*PRE*HA	1	0 01015312	3 34	0 0800	1	0 01015312	3 34	0 0800

YEAR 1 BERRIES - FACTORIAL ANALYSIS 14 13 THURSDAY, JULY 21, 1988 8

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE TACID

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	7	0 00046314	0 00006616	1 35	0 2694	0 283079	7 1213
ERROR	24	0 00117294	0 00004887		ROOT MSE		TACID MEAN
CORRECTED TOTAL	31	0 00163608			0 00699088		0 09816867

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
STOR	1	0 00000640	0 13	0 7207	1	0 00000640	0 13	0 7207
PRE	1	0 00007736	1 58	0 2205	1	0 00007736	1 58	0 2205
HA	1	0 00000106	0 02	0 8843	1	0 00000106	0 02	0 8843
STOR*HA	1	0 00010949	2 24	0 1475	1	0 00010949	2 24	0 1475
STOR*PRE	1	0 00021540	4 41	0 0465	1	0 00021540	4 41	0 0465
PRE*HA	1	0 00003831	0 78	0 3848	1	0 00003831	0 78	0 3848
STOR*PRE*HA	1	0 00001514	0 31	0 5830	1	0 00001514	0 31	0 5830

YEAR 1 BERRIES - FACTORIAL ANALYSIS 14 13 THURSDAY, JULY 21, 1988 9

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE WEIGHT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	7	222 20218750	31 74316964	21 26	0 0001	0 861133	8 4141
ERROR	24	35 83250000	1 49302083		ROOT MSE		WEIGHT MEAN
CORRECTED TOTAL	31	258 03468750			1 22189232		14 52187500

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
STOR	1	1 95031250	1 31	0 2643	1	1 95031250	1 31	0 2643
PRE	1	1 48781250	1 00	0 3281	1	1 48781250	1 00	0 3281
HA	1	203 51531250	136 31	0 0001	1	203 51531250	136 31	0 0001
STOR*HA	1	1 16281250	0 78	0 3863	1	1 16281250	0 78	0 3863
STOR*PRE	1	9 57031250	6 41	0 0183	1	9 57031250	6 41	0 0183
PRE*HA	1	4 42531250	2 96	0 0980	1	4 42531250	2 96	0 0980
STOR*PRE*HA	1	0 09031250	0 06	0 8078	1	0 09031250	0 06	0 8078

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE TSS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	7	0 00058129	0 00008304	0 57	0 7744	0 142133	3 8570
ERROR	24	0 00350849	0 00014619		ROOT MSE		TSS MEAN
CORRECTED TOTAL	31	0 00408978			0 01209078		0 31347578

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
STOR	1	0 00002306	0 16	0 6948	1	0 00002306	0 16	0 6948
PRE	1	0 00009195	0 63	0 4355	1	0 00009195	0 63	0 4355
HA	1	0 00041801	2 86	0 1038	1	0 00041801	2 86	0 1038
STOR*HA	1	0 00000191	0 01	0 9099	1	0 00000191	0 01	0 9099
STOR*PRE	1	0 00003085	0 21	0 6501	1	0 00003085	0 21	0 6501
PRE*HA	1	0 00000285	0 02	0 8902	1	0 00000285	0 02	0 8902
STOR*PRE*HA	1	0 00001266	0 09	0 7711	1	0 00001266	0 09	0 7711

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE NEWT1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	7	9 84138026	1 40591147	13 60	0 0001	0 798649	9 0839
ERROR	24	2 48115913	0 10338163		ROOT MSE		NEWT1 MEAN
CORRECTED TOTAL	31	12 32253939			0 32153014		3 53957062

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
STOR	1	4 65402591	45 02	0 0001	1	4 65402591	45 02	0 0001
PRE	1	0 17034993	1 65	0 2115	1	0 17034993	1 65	0 2115
HA	1	1 44846157	14 01	0 0010	1	1 44846157	14 01	0 0010
STOR*HA	1	0 15089820	1 46	0 2388	1	0 15089820	1 46	0 2388
STOR*PRE	1	0 02771600	0 27	0 6094	1	0 02771600	0 27	0 6094
PRE*HA	1	1 46520665	14 17	0 0010	1	1 46520665	14 17	0 0010
STOR*PRE*HA	1	1 92472200	18 62	0 0002	1	1 92472200	18 62	0 0002

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE NEWT2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	7	23 73222826	3 39031832	5 51	0 0007	0 616300	13 8625
ERROR	24	14 77539308	0 61564138		ROOT MSE		NEWT2 MEAN
CORRECTED TOTAL	31	38 50762134			0 78462818		5 66006344

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
STOR	1	5 75217906	9 34	0 0054	1	5 75217906	9 34	0 0054
PRE	1	4 12384019	6 70	0 0161	1	4 12384019	6 70	0 0161
HA	1	3 97034361	6 45	0 0180	1	3 97034361	6 45	0 0180
STOR*HA	1	5 53793344	9 00	0 0062	1	5 53793344	9 00	0 0062
STOR*PRE	1	0 26886261	0 44	0 5150	1	0 26886261	0 44	0 5150
PRE*HA	1	2 58432724	4 20	0.0516	1	2 58432724	4 20	0 0516
STOR*PRE*HA	1	1 49474211	2 43	0 1323	1	1 49474211	2 43	0 1323

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TGOOD
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GLNERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE= 0126678
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 08213

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	STOR
A	1 11376	16	CA
B	0 83940	16	RA

121

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TLOSS
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=9 5E-04
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 02251

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	STOR
A	0 13372	16	RA
B	0. 10719	16	CA

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TMOIST
NOTE· THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0. 05 DF=24 MSE=1 3E-04
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 00832

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY GROUPING	MEAN	N	STOR
A	1. 235972	16	RA
A			
A	1. 231156	16	CA

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE PH
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE= 0030385
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 04023

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	STOR
A	3 48875	16	CA
A			
A	3 48687	16	RA

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: TACID
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=4 9E-05
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE=0 0051

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	STOR
A	0.098616	16	CA
A			
A	0.097722	16	RA

YEAR 1 BERRIES - FACTORIAL ANALYSIS

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE WEIGHT
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=1 49302
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 89166

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	STOR
A	14 7687	16	CA
A			
A	14 2750	16	RA

YEAR 1 BERRIES - FACTORIAL ANALYSIS

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: TSS
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=1.5E-04
CRITICAL VALUE OF STUDENTIZED RANGE=2.919
MINIMUM SIGNIFICANT DIFFERENCE=.00882

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY GROUPING	MEAN	N	STOR
A	0.314325	16	CA
A			
A	0.312627	16	RA

YEAR 1 BERRIES - FACTORIAL ANALYSIS 14:13 THURSDAY, JULY 21, 1988 20

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE NEWT1
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0.05 DF=24 MSE=0 103382
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 23463

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	STOR
A	3.9209	16	CA
B	3.1582	16	RA

YEAR 1 BERRIES - FACTORIAL ANALYSIS 14:13 THURSDAY, JULY 21, 1988 21

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE NEWT2
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0.05 DF=24 MSE=0 615641
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 57257

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	STOR
A	6 0840	16	CA
B	5 2361	16	RA

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TGOOD
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE= 0126678
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 08213

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	PRE
A	1. 00487	16	OO
A			
A	0 94829	16	CO

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: TLOSS
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0. 05 DF=24 MSE=9. 5E-04
CRITICAL VALUE OF STUDENTIZED RANGE=2. 919
MINIMUM SIGNIFICANT DIFFERENCE= 02251

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY GROUPING	MEAN	N	PRE
A	0 12307	16	CO
A			
A	0. 11784	16	OO

YEAR 1 BERRIES - FACTORIAL ANALYSIS 14 13 THURSDAY, JULY 21, 1988 24

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE. TMOIST
NOTE· THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=1 3E-04
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 00832

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY GROUPING	MEAN	N	PRE
A	1.236083	16	CO
A			
A	1.231046	16	OO

YEAR 1 BERRIES - FACTORIAL ANALYSIS 14:13 THURSDAY, JULY 21, 1988 25

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE. PH
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE= 0030385
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 04023

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	PRE
A	3.49000	16	OO
A			
A	3 48562	16	CO

YEAR 1 BERRIES - FACTORIAL ANALYSIS 14 13 THURSDAY, JULY 21, 1988 26

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TACID
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=4 9E-05
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE=0 0051

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	PRE
A	0 099723	16	CO
A			
A	0.096614	16	OO

YEAR 1 BERRIES - FACTORIAL ANALYSIS 14·13 THURSDAY, JULY 21, 1988 27

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE WEIGHT
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0.05 DF=24 MSE=1 49302
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE=.89166

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY GROUPING	MEAN	N	PRE
A	14.7375	16	CO
A			
A	14.3062	16	OO

YEAR 1 BERRIES - FACTORIAL ANALYSIS　　14.13 THURSDAY, JULY 21, 1988　　28

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TSS
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=1.5E-04
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 00882

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	PRE
A	0.315171	16	CO
A			
A	0 311781	16	OO

YEAR 1 BERRIES - FACTORIAL ANALYSIS　　14:13 THURSDAY, JULY 21, 1988　　29

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: NEWT1
NOTE· THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERPOR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=0 103382
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 23463

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	PRE
A	3.6125	16	CO
A			
A	3 4666	16	OO

YEAR 1 BERRIES - FACTORIAL ANALYSIS 14 13 THURSDAY, JULY 21, 1988 30

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE NEWT2
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=0 615641
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 57257

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	PRE
A	6 0190	16	CO
B	5 3011	16	OO

YEAR 1 BERRIES - FACTORIAL ANALYSIS 14·13 THURSDAY, JULY 21, 1988 31

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: TGOOD
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE= 0126678
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 08213

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	HA
A	0 99399	16	1
A			
A	0.95918	16	2

YEAR 1 BERRIES - FACTORIAL ANALYSIS 14:13 THURSDAY, JULY 21, 1988 32

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TLOSS
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=9 5E-04
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 02251

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	HA
A	0.14155	16	1
B	0.09936	16	2

YEAR 1 BERRIES - FACTORIAL ANALYSIS 14.13 THURSDAY, JULY 21, 1988 33

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TMOIST
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=1 3E-04
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 00832

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY GROUPING	MEAN	N	HA
A	1 238428	16	1
B	1.228701	16	2

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE PH
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE= 0030385
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 04023

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	HA
A	3 51250	16	1
B	3 46312	16	2

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE. TACID
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=4 9E-05
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE=0 0051

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	HA
A	0.098350	16	1
A			
A	0.097987	16	2

YEAR 1 BERRIES - FACTORIAL ANALYSIS   14 13 THURSDAY, JULY 21, 1988   36

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE WEIGHT
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=1 49302
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 89166

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	HA
A	17.0437	16	1
B	12 0000	16	2

YEAR 1 BERRIES - FACTORIAL ANALYSIS   14·13 THURSDAY, JULY 21, 1988   37

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TSS
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=1 5E-04
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE=. 00882

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY GROUPING	MEAN	N	HA
A	0. 317090	16	1
A			
A	0. 309862	16	2

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE NEWT1
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=0 103382
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 23463

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	HA
A	3.7523	16	1
B	3.3268	16	2

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE NEWT2
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=0 615641
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE=.57257

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY GROUPING	MEAN	N	HA
A	6 0123	16	1
B	5.3078	16	2

YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED 14:13 THURSDAY, JULY 21, 1988 40

GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
YEAR	2	1 2
HA	2	1 2
STOR	2	CA RA

NUMBER OF OBSERVATIONS IN DATA SET = 32

YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED 14.13 THURSDAY, JULY 21, 1988 41

GENERAL LINEAR MODELS PROCEDURE

SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V.
0 70387174	0. 10055311	9. 87	0 0001	0 742217	10 3555
0 24446545	0. 01018606		ROOT MSE		TGOOD MEAN
0 94833719			0 10092602		0 97461060

TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
0 02930503	2 88	0 1028	1	0 02930503	2 88	0 1028
0 00005132	0 01	0 9440	1	0 00005132	0 01	0 9440
0. 57929612	56. 87	0 0001	1	0 57929612	56 87	0 0001
0 01057804	1 04	0. 3183	1	0 01057804	1 04	0 3183
0 01025641	1 01	0 3257	1	0 01025641	1 01	0 3257
0 01617758	1 59	0 2197	1	0 01617758	1 59	0 2197
0 05820724	5 71	0 0250	1	0 05820724	5 71	0 0250

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE TLOSS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	7	0 01644067	0 00234867	7 43	0 0001	0 684141	15 1028
ERROR	24	0 00759045	0 00031627		ROOT MSE		TLOSS MEAN
CORRECTED TOTAL	31	0 02403112			0 01778395		0 11775286

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
YEAR	1	0 00000027	0 00	0 9769	1	0 00000027	0 00	0 9769
HA	1	0 00895083	28 30	0 0001	1	0 00895083	28 30	0 0001
STOR	1	0 00000164	0 01	0 9432	1	0 00000164	0 01	0 9432
YEAR*HA	1	0 00304214	9 62	0 0049	1	0 00304214	9 62	0 0049
YEAR*STOR	1	0 00130238	4 12	0 0537	1	0 00130238	4 12	0 0537
HA*STOR	1	0 00308388	9 75	0 0046	1	0 00308388	9 75	0 0046
YEAR*HA*STOR	1	0 00005954	0 19	0 6683	1	0 00005954	0 19	0 6683

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE TMOIST

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	7	0 00103149	0 00014736	1 69	0 1589	0 330284	0 7558
ERROR	24	0 00209154	0 00008715		ROOT MSE		TMOIST MEAN
CORRECTED TOTAL	31	0 00312303			0 00933528		1 23510734

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
YEAR	1	0. 00052787	6 06	0 0214	1	0 00052787	6 06	0 0214
HA	1	0 00019225	2 21	0 1505	1	0 00019225	2 21	0 1505
STOR	1	0 00010036	1 15	0 2939	1	0 00010036	1 15	0 2939
YEAR*HA	1	0 00017274	1 98	0 1720	1	0 00017274	1.98	0 1720
YEAR*STOR	1	0. 00002944	0 34	0 5665	1	0 00002944	0 34	0 5665
HA*STOR	1	0. 00000005	0. 00	0 9817	1	0 00000005	0 00	0 9817
YEAR*HA*STOR	1	0 00000878	0 10	0 7537	1	0 00000878	0 10	0 7537

YEAR 1 & 2 BEPRIES - HIGH CO2 TREATMENT EXCLUDED   14 13 THURSDAY, JULY 21, 1988   44

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE PH

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	7	0 05302188	0 00757455	1 83	0 1281	0 347578	1 8410
ERROR	24	0 09952500	0 00414687		ROOT MSE		PH MEAN
CORRECTED TOTAL	31	0 15254687			0 06439623		3 49781250

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
YEAR	1	0 00195312	0 47	0 4991	1	0 00195312	0 47	0 4991
HA	1	0 03850313	9 28	0 0055	1	0 03850313	9 28	0 0055
STOR	1	0 00015312	0 04	0 8492	1	0 00015312	0 04	0 8492
YEAR*HA	1	0 00262813	0 63	0 4338	1	0 00262813	0 63	0 4338
YEAR*STOP	1	0 00025312	0 06	0 8070	1	0 00025312	0 06	0 8070
HA*STOR	1	0 00007812	0 02	0 8920	1	0 00007812	0 02	0 8920
YEAR*HA*STOR	1	0 00945313	2 28	0 1441	1	0 00945313	2 28	0 1441

YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED   14 13 THURSDAY, JULY 21, 1988   45

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE TACID

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	7	0 00060107	0 00008587	1 78	0 1383	0 341548	7 0543
ERROR	24	0 00115878	0 00004828		ROOT MSE		TACID MEAN
CORRECTED TOTAL	31	0 00175985			0 00694856		0 09850107

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PP > F
YEAR	1	0 00011397	2 36	0 1375	1	0 00011397	2 36	0 1375
HA	1	0 00006523	1 35	0 2565	1	0 00006523	1 35	0 2565
STOR	1	0 00000002	0 00	0 9837	1	0 00000002	0 00	0 9837
YEAR*HA	1	0 00000850	0 18	0 6785	1	0 00000850	0 18	0 6785
YEAR*STOR	1	0 00029112	6 03	0 0217	1	0 00029112	6 03	0 0217
HA*STOR	1	0 00010774	2 23	0 1483	1	0 00010774	2 23	0 1483
YEAR*HA*STOR	1	0 00001449	0 30	0 5888	1	0 00001449	0 30	0 5888

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE WEIGHT

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	7	270 78000000	38 68285714	23 01	0 0001	0 870339	9 9537
ERROR	24	40 34000000	1 68083333		ROOT MSE		WEIGHT MEAN
CORRECTED TOTAL	31	311 12000000			1 29646957		13 02500000

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
YEAR	1	52 53125000	31 25	0 0001	1	52 53125000	31 25	0 0001
HA	1	202 00500000	120 18	0 0001	1	202 00500000	120 18	0 0001
STOR	1	4 06125000	2 42	0 1332	1	4 06125000	2 42	0 1332
YEAR*HA	1	4 65125000	2 77	0 1092	1	4 65125000	2 77	0 1092
YEAR*STOR	1	6 12500000	3 64	0 0683	1	6 12500000	3 64	0 0683
HA*STOR	1	1 36125000	0 81	0 3771	1	1 36125000	0 81	0 3771
YEAR*HA*STOR	1	0 04500000	0 03	0 8714	1	0 04500000	0 03	0 8714

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE TSS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	7	0 00288678	0 00041240	3 31	0 0131	0 491188	3 5346
ERROR	24	0 00299036	0 00012460		ROOT MSE		TSS MEAN
CORRECTED TOTAL	31	0 00587714			0 01116236		0 31580518

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
YEAR	1	0 00051830	4 16	0 0526	1	0 00051830	4 16	0 0526
HA	1	0 00000156	0 01	0 9118	1	0 00000156	0 01	0 9118
STOR	1	0 00067121	5 39	0 0291	1	0 00067121	5 39	0 0291
YEAR*HA	1	0 00043611	3 50	0 0736	1	0 00043611	3 50	0 0736
YEAR*STOR	1	0 00063278	5 08	0 0336	1	0 00063278	5 08	0 0336
HA*STOR	1	0 00040003	3 21	0 0858	1	0 00040003	3 21	0 0858
YEAR*HA*STOR	1	0 00022680	1 82	0 1899	1	0 00022680	1 82	0 1899

YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED 14 13 THURSDAY, JULY 21, 1988 48

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE NEWT1

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	7	5 56619678	0 79517097	3 46	0 0106	0 502006	13 9140
ERROR	24	5 52171465	0 23007144		ROOT MSE		NEWT1 MEAN
CORRECTED TOTAL	31	11 08791143			0 47965763		3 44729531

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
YEAR	1	0 01193628	0 05	0 8218	1	0 01193628	0 05	0 8218
HA	1	1 21265004	5 27	0 0307	1	1 21265004	5 27	0 0307
STOR	1	0 59553605	2 59	0 1207	1	0 59553605	2 59	0 1207
YEAR*HA	1	1 72337503	7 49	0 0115	1	1 72337503	7 49	0 0115
YEAR*STOR	1	1 48627334	6 46	0 0179	1	1 48627334	6 46	0 0179
HA*STOR	1	0 13136528	0 57	0 4572	1	0 13136528	0 57	0 4572
YEAR*HA*STOR	1	0 40506075	1 76	0 1970	1	0 40506075	1 76	0 1970

YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED 14 13 THURSDAY, JULY 21, 1988 49

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE NEWT2

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C V
MODEL	7	14 83580229	2 11940033	4 47	0 0026	0 565703	13 4955
ERROR	24	11 38961461	0 47456728		ROOT MSE		NEWT2 MEAN
CORRECTED TOTAL	31	26 22541690			0 68888843		5 10457219

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
YEAR	1	1 23567453	2 60	0 1197	1	1 23567453	2 60	0 1197
HA	1	9 97258917	21 01	0 0001	1	9 97258917	21 01	0 0001
STOR	1	1 77844614	3 75	0 0648	1	1 77844614	3 75	0 0648
YEAR*HA	1	0 19555476	0 41	0 5270	1	0 19555476	0 41	0 5270
YEAR*STOR	1	0 29840709	0 63	0 4356	1	0 29840709	0 63	0 4356
HA*STOR	1	1 35404493	2 85	0 1041	1	1 35404493	2 85	0 1041
YEAR*HA*STOR	1	0 00108566	0 00	0 9622	1	0 00108566	0 00	0 9622

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TGOOD
NOTE. THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE= 0101861
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 07365

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	STOR
A	1 10916	16	CA
B	0 84006	16	RA

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TLOSS
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=3 2E-04
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE=.01298

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY GROUPING	MEAN	N	STOR
A	0 117979	16	RA
A			
A	0.117527	16	CA

YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED 14·13 THURSDAY, JULY 21, 1988 52

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TMOIST
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=8 7E-05
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 00681

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	STOR
A	1 236878	16	CA
A			
A	1.233336	16	RA

YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED 14·13 THURSDAY, JULY 21, 1988 53

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE PH
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE= 0041469
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 04699

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	STOR
A	3 50000	16	RA
A			
A	3 49562	16	CA

YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED 14 13 THURSDAY, JULY 21, 1988 54

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TACID
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=4 8E-05
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 00507

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	STOR
A	0 098526	16	CA
A			
A	0 098476	16	RA

YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED 14.13 THURSDAY, JULY 21, 1988 55

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE WEIGHT
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=1 68083
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 94608

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	STOR
A	13.3812	16	CA
A			
A	12 6687	16	RA

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TSS
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=1 2E-04
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 00815

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	STOR
A	0 320385	16	RA
B	0 311225	16	CA

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE NEWT1
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=0 230071
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 35002

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	STOR
A	3. 5837	16	CA
A			
A	3 3109	16	RA

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE NEWT2
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=0 474567
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 50271

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	STOR
A	5 3403	16	CA
A			
A	4 8688	16	RA

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE· TGOOD
NOTE· THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0.05 DF=24 MSE= 0101861
CRITICAL VALUE OF STUDENTIZED RANGE=2.919
MINIMUM SIGNIFICANT DIFFERENCE= 07365

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY GROUPING	MEAN	N	YEAR
A	1 00487	16	1
A			
A	0.94435	16	2

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TLOSS
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=3 2E-04
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 01298

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	YEAR
A	0. 117845	16	1
A			
A	0 117661	16	2

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TMOIST
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0. 05 DF=24 MSE=8 7E-05
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 00681

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	YEAR
A	1 239169	16	2
B	1. 231046	16	1

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE PH
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE= 0041469
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 04699

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	YEAR
A	3 50562	16	2
A			
A	3 49000	16	1

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TACID
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=4 8E-05
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 00507

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	YEAR
A	0 100388	16	2
A			
A	0.096614	16	1

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE WEIGHT
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=1 68083
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 94608

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	YEAR
A	14 3062	16	1
B	11 7437	16	2

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TSS
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=1 2E-04
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 00815

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	YEAR
A	0 319830	16	2
A			
A	0 311781	16	1

YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED   14 13 THURSDAY, JULY 21, 1988   66

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE NEWT1
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE.
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=0 230071
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 35002

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	YEAR
A	3 4666	16	1
A			
A	3. 4280	16	2

YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED   14. 13 THURSDAY, JULY 21, 1988   67

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE NEWT2
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=0. 474567
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 50271

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

TUKEY GROUPING	MEAN	N	YEAR
A	5 3011	16	1
A			
A	4 9081	16	2

YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED   14·13 THURSDAY, JULY 21, 1988   68

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TGOOD
NOTE· THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE= 0101861
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 07365

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	HA
A	0 97588	16	2
A			
A	0 97334	16	1

YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED   14.13 THURSDAY, JULY 21, 1988   69

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TLOSS
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=3 2E-04
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 01298

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	HA
A	0 134477	16	1
B	0 101028	16	2

149

YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED 14:13 THURSDAY, JULY 21, 1988 70

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TMOIST
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=8 7E-05
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 00681

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	HA
A	1 237558	16	1
A			
A	1 232656	16	2

YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED 14:13 THURSDAY, JULY 21, 1988 71

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE PH
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0.05 DF=24 MSE=.0041469
CRITICAL VALUE OF STUDENTIZED RANGE=2.919
MINIMUM SIGNIFICANT DIFFERENCE= 04699

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	HA
A	3.53250	16	1
B	3.46312	16	2

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE TACID
NOTE. THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=4 8E-05
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 00507

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	HA
A	0 099929	16	2
A			
A	0 097073	16	1

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE: WEIGHT
NOTE. THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=1 68083
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 94608

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	HA
A	15 5375	16	1
B	10. 5125	16	2

```
YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED          14 13 THURSDAY, JULY 21, 1988    74
               GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE  TSS
NOTE  THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
      BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

        ALPHA=0 05  DF=24  MSE=1 2E-04
        CRITICAL VALUE OF STUDENTIZED RANGE=2 919
        MINIMUM SIGNIFICANT DIFFERENCE= 00815

 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

      TUKEY     GROUPING              MEAN       N  HA

                       A         0 316026       16  1
                       A
                       A         0 315584       16  2
```

```
YEAR 1 & 2 BERRIES - HIGH CO2 TREATMENT EXCLUDED          14 13 THURSDAY, JULY 21, 1988    75
               GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE  NEWT1
NOTE: THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE,
      BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

        ALPHA=0.05  DF=24  MSE=0 230071
        CRITICAL VALUE OF STUDENTIZED RANGE=2 919
        MINIMUM SIGNIFICANT DIFFERENCE= 35002

 MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

      TUKEY     GROUPING              MEAN       N  HA

                       A           3.6420       16  1

                       B           3.2526       16  2
```

GENERAL LINEAR MODELS PROCEDURE

TUKEY'S STUDENTIZED RANGE (HSD) TEST FOR VARIABLE NEWT2
NOTE THIS TEST CONTROLS THE TYPE I EXPERIMENTWISE ERROR RATE, BUT GENERALLY HAS A HIGHER TYPE II ERROR RATE THAN REGWQ

ALPHA=0 05 DF=24 MSE=0 474567
CRITICAL VALUE OF STUDENTIZED RANGE=2 919
MINIMUM SIGNIFICANT DIFFERENCE= 50271

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

TUKEY GROUPING	MEAN	N	HA
A	5 6628	16	1
B	4.5463	16	2

Appendix D. Sample calculations to determine the amount of ice necessary to maintain CA in an enclosure.

A) DATA

i) enclosure

- volume : 3 m^3
- free space : 50%
- air change per hour : 1 air change per
: 1.5 m^3/h
: poor airtightness

ii) dry ice

- sublimation rate at 5^oC: see Figure 22

iii) volume of gaseous CO_2 per kg of dry ice sublimated

V_kg = 0.0224 m^3/mole X (1000g / 40g/mole)
V_kg = 0.56 m^3/kg

B) AMOUNT OF DRY ICE

i) rate of sublimation required

Given a CA with 20% CO_2, a fifth of the volume of t atmosphere is gaseous CO_2 and a fifth of the volume of air ventilated every hour is CO_2. Hence,

CO_2 consumed = 1.5 m^3/h X 20% / 0.56 m^3/kg
= 0.54 kg CO_2/hr

ii) amount of dry ice matching the rate of sublimation

Referring to Figure 22, a block of dry ice weighing between 16 to 20 kg would lose 0.5 kg/hr at 5 ^oC.