Agri. & Biosys. Eng. Vol. 3(1):10-17(2002)

Apple Quality as Affected by the Precooling Rate and O_2 Pulldown Rate in Controlled Atmosphere Storage

P. V. Mahajan, T. K. Goswami

Abstract: Quality attributes of apple are greatly affected by the cooling rate and environmental conditions during storage. Studies were conducted to evaluate the effect of cooling rate on different quality attributes of apple. The effect of O_2 pulldown rate of the CA chamber on the quality of apple was also determined. Two methods were used viz. conventional CA procedure and rapid CA procedure. Apples stored by medium and slow cooling methods lost its flesh firmness significantly from an initial level of 4.55 kg to 2.83 kg and 2.27 kg, respectively on 35 days after storage whereas, in rapid cooling, the firmness level changed from 4.55 kg to 3.20 kg on 35 days after storage. At the end of 35 days of storage, titratable acidity decreased insignificantly from an initial value of 0.241% to 0.239% in the case of rapid CA whereas in the case of conventional CA it dropped significantly to 0.215% from its initial level. The initial flesh firmness of 4.55 kg also changed significantly to 4.05 kg on 35 days after storage in conventional CA whereas in rapid CA it changed to 4.36 kg, which was found to be non-significant at 5% level of significance. Total soluble solids increased from an initial level of 12.43° Bx to 12.60° Bx on 35 days after storage in rapid CA whereas it increased to 13.07° Bx in conventional CA. Ascorbic acid content of apple juice decreased insignificantly from 6.67 mg/100 mL to 5.87 mg/100 mL on 35 days after storage in rapid CA whereas in conventional CA, it decreased significantly to 5.27 mg/100 mL from its initial level.

Keywords: Apple, Postharvest, Controlled atmosphere storage, Modified atmosphere packaging, Precooling

Introduction

The living cells of harvested plant products respire continuously, utilizing O_2 from the surrounding environment and releasing CO_2(Kays, 1991; Hagger et al., 1992). In general, there is an inverse relationship between respiration rate and storage life of agriculture products, lower the respiration rate longer the shelf-life. Based on this, Kidd and West developed a Controlled Atmosphere(CA) storage system for the preservation of fresh fruits and vegetables(Metlitskii et al., 1983). It involves a system in which the storage atmosphere differs substantially from normal atmosphere with respect to the proportion of N_2, O_2 and CO_2 concentrations(Kader, 1980; Metlitskii et al., 1983; Bartsch and Blanpied, 1990). Besides reducing the temperature, the recommended proportion of O_2 and CO_2 concentrations of storage atmosphere are established, monitored and maintained throughout the storage period by employing some external means. Before pulling down the O_2 concentration of the storage atmosphere, product has to be cooled down to the desired level to avoid high rate of respiration, preventing to high heat of respiration(Metlitskii et al., 1983). Hence, immediate cooling of fruits and vegetables after their harvest is essential, which will also initiate the O_2 reduction equipment working. According to Kupferman(1991) fruit with temperature greater than 15.5℃ should be cooled prior to lowering the O_2 level.

At present many different methods and devices are being used for establishing and maintaining a given gas regime in CA storage(Metlitskii et al., 1983). These equipments are either costly or take long time to establish the desired CA conditions. During the establishment period the various quality losses of stored produce occurs. These losses could be avoided by selecting the proper refrigeration system as well as O_2 pulldown equipment. Rapid cooling is difficult to accomplish with conventional refrigeration system due

The authors are Dr. **T. K. Goswami,** Assistant Professor and **P. V. Mahajan**, Research Scholar, Post Harvest Technology Center, Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur, India.
Corresponding author: Dr. T. K. Goswami, Assistant Professor, Post Harvest Technology Center, Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur 721-302, West Bengal, India. Tel: 91-03222-77362, Fax: 91-03222-55303. E-mail: tkg@agfe.iitkgp.ernet.in

to the requirement of the fast filling of the CA storage rooms necessitating increasing demands on available refrigeration capacity(Watkins et al., 1997). Hence, CA storages require more refrigeration capacity than conventional cold storages(Ryall and Pentzer, 1982). Once the fruit is cooled, only about 10 per cent of the installed evaporator capacity is needed to maintain long-term storage temperatures(Waelti, 1994). Rest of the installed evaporator capacity remains idle during the maintenance phase. Hence, there is a need of a system, which can be used to remove the field heat of the produce rapidly in addition to achieving the required O_2 concentration within a reasonably short period of time.

Cryogenic fluids such liquid nitrogen(LN_2) can effectively be used to achieve both of these objectives. Liquid nitrogen, due to its inertness, is an excellent means of rapid atmosphere establishment in commercial CA storage rooms because the O_2 concentration can be reduced to the storage level in a few hours(Bartsch, 1986). It boils at -195.6℃ at atmospheric pressure and gives latent heat of 199.58 kJ/kg(ASHRAE Handbook, 1990). Both latent heat and sensible heat, which may be available from vaporized N_2 gas can be used for cooling of fresh produce. In view of the price of cryogenic fluids available in the market, cryogenic cooling processes can only be economically justifiable when the use is minimum i.e. if it is used for initial cooling to remove the field heat of the produce and for reducing the initial O_2 concentration of the storage atmosphere. Once the temperature and O_2 concentration have reached the desired level, shifting of LN_2 refrigeration system to the mechanical refrigeration system(designed to supplement the maintenance phase without considering the field heat) can be of a suitable choice. Hence, study was conducted to investigate the effect of LN_2 assisted cooling and O_2 pulldown on the quality attributes of apple.

Materials and Methods

1. Raw Materials

Freshly harvested apples cv. Red delicious were collected from an orchard(Chaman Orchards, Kashmir, India) during the harvest seasons of September 1999 and 2000 and transported to the laboratory within 72 hours of harvesting. Damage and immature/small fruits were discarded and only the good fruits were taken for the study. Flesh firmness of apple cubes and starch-iodine index(Chu, 1997) of cut apples were found to be 4.55 kg and 4.2, respectively indicating that the fruits were physically mature.

2. Effect of cooling rate on apple quality

Study was conducted to evaluate the effect of cooling rate obtained by different methods viz. slow, medium and rapid cooling rates. In slow cooling, apples were cooled to 1℃ within 14 days(approximate cooldown time of commercial cold storages) by dropping the temperature at the rate of about 2℃ per day. In medium cooling, apples were cooled to 1℃ within 7 days by dropping the temperature at the rate of about 4℃ per day. In rapid cooling, apples were cooled to 1℃ temperature almost instantaneously with the help of cold N_2 vapour obtained by evaporating LN_2. Apples kept in ambient open atmosphere were taken as control.

3. Effect of O_2 pulldown rate on apple quality

The effect of O_2 pulldown rate of the CA chamber on the quality of apple was determined.

(1) CA conditions for apple

The basic purpose of any CA storage is to reduce the rate of respiration of the stored commodity. Reduction of O_2 concentration to its lowest permissible level is an effective tool to minimize the respiration rate of the fruit. For red delicious variety of apple, the lowest respiration rate was reported to be at 2% CO_2 concentration, 1 to 1.5% O_2 concentration, and at a storage temperature of 1℃(Kupferman, 1997; Bohling and Hellickson, 1998). Hence, for the present study on a laboratory scale model, storage gas regime of 1~2% O_2 and 1~2% CO_2 were selected. These storage gas regimes were also found to be optimum by Eksteen and Truter(1987) for delicious varieties of apple. The temperature of the CA chamber was maintained at 1℃. The RH of the CA chamber was maintained at 92 to 95% by using the saturated solution of potassium nitrate(Celis and Stenning, 1995). Two methods viz. conventional CA procedure and rapid CA procedure were used to study the effect of O_2 pulldown rate on quality of apple.

(2) Conventional CA procedure

For conventional CA procedure, a flow through system of size $0.144 \times 0.178 \times 0.227$ m having purg-

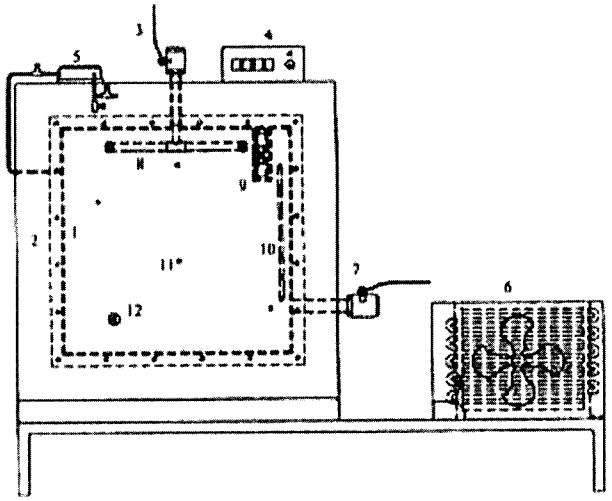
ing arrangement for O_2, CO_2 and N_2 gases was used. The chamber had been fitted with neoprene rubber to ensure the gas tightness of the chamber and provision for inlet and outlet for the gases on the top. The temperature of apple kept in the CA chamber was immediately reduced to 1℃. Then, the O_2 concentration was brought down to 1.5% in 20 days(Ryall and Pentzer, 1982; Lau, 1985) at the rate of about 1 % drop per day. The CO_2 concentration of 1.5% was kept constant throughout the storage period. The CA chamber was continuously ventilated with O_2, N_2 and CO_2 gases at a predetermined rate according to the procedure given by Peterson et al.(1989) so as to achieve the desired gas composition in the CA chamber at any given point of time during the storage period. The composition of the gas mixture was verified every day by taking gas sample from the storage space and analyzing it by a gas chromatograph.

(3) Rapid CA procedure

In rapid CA procedure, O_2 pulldown as well as temperature reduction were achieved rapidly with the help of LN_2. The properties of LN_2 viz. inertness and low boiling point of −195.6℃ were used for creating low O_2 atmosphere and for reducing the temperature of apple, respectively(Bartsch, 1986). An airtight CA chamber of about 0.495 m high, 0.494 m wide and 0.298 m long as shown in Fig. 1 was constructed for LN_2 flushing. LN_2 was flushed through a perforated copper tube of 0.3 m long and 0.019 m outer diameter. The O_2 and temperature sensors were fixed inside the CA chamber to maintain their desired levels. The CO_2 concentration was increased through an external supply.

4. Gas Analysis

Storage gas sample of about 100 μL was taken periodically with the help of an airtight micro syringe and was analyzed for O_2 and CO_2 concentrations using gas chromatograph(Nucon AIMIL 5700, New Delhi, India) equipped with a thermal conductivity detector. Carrier gas was set at a flow rate of 60 mL/min. Oven temperature was kept at 40℃ whereas injector and detector were set at 60℃. A column packed with porapack-Q(80~100 mesh, 1.83 m long) was used for CO_2 separation from O_2 and N_2 and a column packed with molecular sieve 13X(20~80 mesh, 1.83 m long) was used for O_2 and N_2 separation.



Legends :

1 Stainless steel chamber
2 Thermocole insulation
3 LN_1 flushing valvs
4 Temperature controller
5 Pump
6 Refrigeration system
7 Vent valve
8 Distributor hender
9 Fun
10 Evaporator coil
11 Thrmocouples (symbolo)
12 Septum

All dimensions are in mm

Fig. 1 Details of the CA chamber having LN_2 flusing facility.

5. Assessment of Fruit Quality

The various quality parameters viz. flesh firmness, weight loss, total soluble solids, ascorbic acid, and titratable acidity were assessed as appended below:

(1) Flesh Firmness

A texture analyzer(Stable Micro Systems TA-XTi, UK) was used to determine flesh firmness of apple. The instrument settings used were: pre-test speed, test speed and post-test speed: 0.5 mm/s, trigger force: 30 g, data acquisition rate: 200 pps and load cell: 25 kg. Stainless steel cylinder probe of 5 mm diameter was used. Firmness was recorded as the maximum force required to compress the product by 3 mm.

(2) Weight Loss

Weight loss of fruit during storage period was recorded with the help of a precision electronic balance(Essae Teraoka Ltd, USA). Three fruits were weighed and marked immediately prior to closure of

the CA chamber and the same fruits were weighed during the entire experiment. Weight loss was expressed in percentage of initial weight of the fruit.

(3) Compositional Analysis of Apple Pulp

Juice was extracted from the apple pulp and filtered through the muslin cloth. Ascorbic acid content was determined by 2,6-Dichlorophenol-Indophenol visual titration method and was expressed in mg per 100 mL of juice(Ranganna, 1986). The titratable acidity of apple pulp was measured by the method given by Ranganna(1986) and was expressed in terms of percent malic acid. Total soluble solids in °Bx of apple juice was determined with the help of hand refractometer(Optex, Japan) having a range of 0 to 32 per cent.

6. Statistical Analysis

Data presented are the average of three replicate measurements along with the standard deviation. Statistical significance was assessed by two-way analysis(Rocha et al., 2000). Significant differences between the treatments were detected using the Waller-Duncan multiple range test(SPSS 7.5, SPSS Inc., Chicago, Illinois). The overall least significant difference(LSD) at 5% level of significance was calculated and used to detect the significant differences among the storage times.

Results and Discussion

1. Effect of cooling rate on quality of apple

The effect of cooling rate on various quality attributes of apple have been given in Figs 2 through 6. Data reported are mean values of three replicates. In control samples, the loss of flesh firmness was significant and reached to 1.65 kg from an initial value of 4.55 kg on 35 days after storage. This loss of flesh firmness was found to have minimized by cooling the apples, the rate of loss being lesser in case of rapid cooling methods. Apples stored using medium and slow cooling methods lost its flesh firmness significantly to 2.83 kg and 2.27 kg, respectively on 35 days after storage whereas in rapid cooling, it reduced to only 3.20 kg after 35 days of storage. Thus, on 35 days after storage, the level of flesh firmness of medium and slow cooled apples was 1.13 and 1.41 times higher than that of rapidly cooled apples.

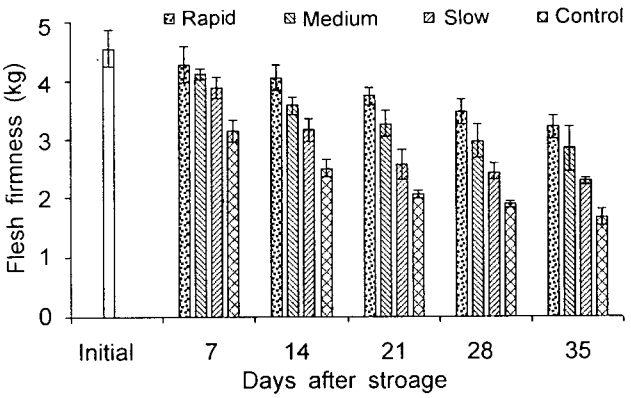


Fig. 2 Effect of cooling rate on flesh firmness of apple ($LSD_{0.05}$ = 0.36).

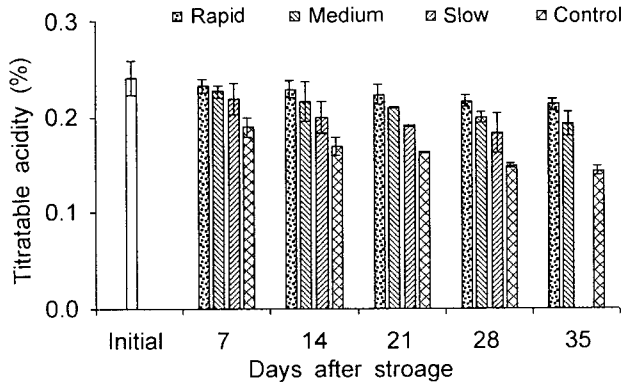


Fig. 3 Effect of cooling rate on titratable acidity of apple ($LSD_{0.05}$ = 0.02).

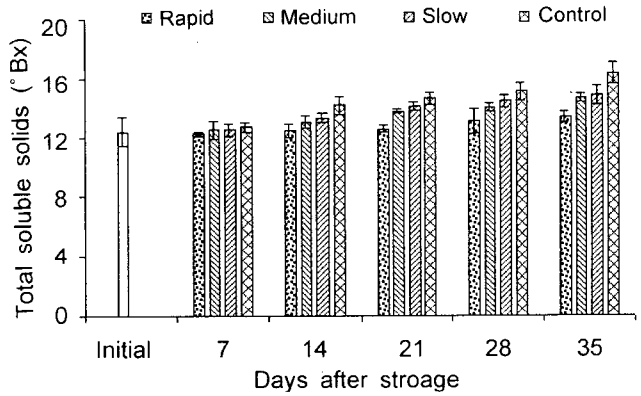


Fig. 4 Effect of cooling rate on total soluble solids of apple ($LSD_{0.05}$ = 0.93).

In slow cooling procedure, the loss of titratable acidity, ascorbic acid and flesh firmness and increase of total soluble solids were significant during the cooldown time i.e. 14 days. Reducing the cooldown time from 14 days to 7 days as in medium cooling, helped to lower the quality losses of apple. Weight loss was also greater in slow and medium cooled

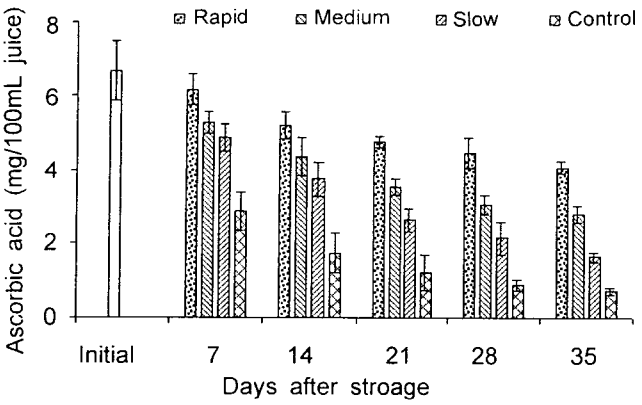


Fig. 5 Effect of cooling rate on ascorbic acid of apple ($LSD_{0.05}$ = 0.76).

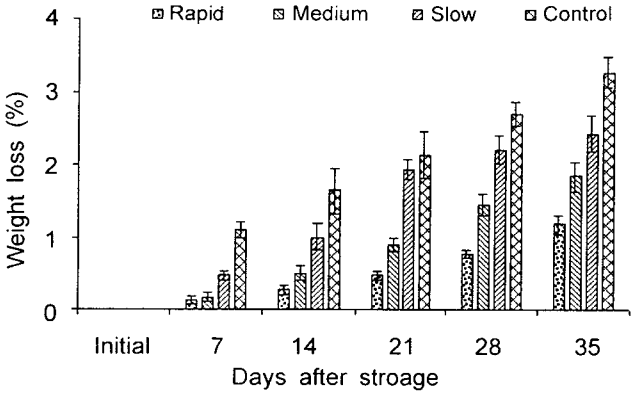


Fig. 6 Effect of cooling rate on weight loss of apple ($LSD_{0.05}$ = 0.25).

apples when compared to rapidly cooled apples. It was found that the losses were appreciably reduced once the apples were cooled to 1℃. Majority of the losses occurred during the cooldown process. In rapid cooling process in which temperature was reduced to 1℃ almost instantaneously, the loss of apple quality did not occur much significantly during the cooldown process and the retention was found to be much higher than those for medium and slow cooled apples. This suggests that the rapid cooling has the beneficial effect to retain the quality of fruit. Rapid cooling also helps in starting the O_2 pulldown operation without further delay.

2. Effect of O_2 pulldown rate on quality of apple

Tables 1 through 5 show the effect of rate of O_2 pulldown of the CA chamber on storability of apple. Rapid CA was found to have almost maintained initial flesh firmness of apple compared to that of conventional CA procedure. The initial level of flesh firmness of apple of 4.55 kg changed significantly to 4.05 kg on 35 days after storage in conventional CA whereas in rapid CA it changed to 4.36 kg, which was found to be non-significant at 5% level of significance. It has been reported that the fruit cells unite with each other by water-insoluble protopectins, which are present in middle lamella and cell walls. Upon ageing and during senescence, the protopectin changes to water-soluble pectin. The loss of firmness in fruits is largely attributed to this change in pectin substances (Mohsenin, 1970). Due to reduction of respiration rate in the CA storage owing to low O_2 concentration, the increase of soluble pectins is retarded which in turn helped in retaining flesh firmness of apple for longer periods.

Titratable acidity was found to have decreased with time. On 35 days after storage, titratable acidity decreased from an initial value of 0.241% to 0.239% in case of rapid CA whereas in the case of conventional CA it dropped to 0.215%. The reason might be due to the reduced decarboxylation of malic acid in fruit stored at low O_2 and high CO_2 concentration.

Total soluble solids content was found to have increased with storage period. In case of rapid CA, its increase was slow and gradual. Total soluble solids increased from an initial level of 12.43 °Bx to 12.60 °Bx on 35 days after storage in rapid CA whereas it increased to 13.07 °Bx in conventional CA. The increase in total soluble solids during storage is attributed to the numerous catabolic processes taking place in the fruit, preparing it for senescence. With time, starch gets hydrolyzed into mono and disaccharides, which in turn may lead to an increase in total soluble solids and sugars. On complete hydrolysis of starch, no further increase in total soluble solids occurs and subsequently it declines since they are the primary substrate for respiration(Nayital et al., 1990).

Initial ascorbic acid content of apple juice of 6.67 mg/100 mL was found to have decreased with the storage period. The rate of decrease was more in conventional CA than that in rapid CA procedure. In rapid CA, it decreased to 5.87 mg/100 mL on 35 days after storage whereas in conventional CA, it decreased significantly to 5.27 mg/100 mL during the establishment period of CA. On 35 days after storage, significant weight loss was occurred in apples when stored in conventional CA compared to that in rapid

Table 1 Effect of rate of O_2 pulldown on flesh firmness of apples

Storage type	Days to achieve O_2 concentration of 1.5 %	Flesh firmness (kg)	
		Initial	After 35 days
Conventional CA	20	4.55 ± 0.31	4.05 ± 0.15
Rapid CA	<1	4.55 ± 0.31	4.36 ± 0.06

The LSD value is 0.44 kg at 0.05 level of significance.

Table 2 Effect of rate of O_2 pulldown on titratable acidity of apples

Storage type	Days to achieve O_2 concentration of 1.5 %	Titratable acidity (%)	
		Initial	After 35 days
Conventional CA	20	0.241 ± 0.018	0.215 ± 0.005
Rapid CA	<1	0.241 ± 0.018	0.239 ± 0.013

The LSD value is 0.027% at 0.05 level of significance.

Table 3 Effect of rate of O_2 pulldown on total soluble solids of apples

Storage type	Days to achieve O_2 concentration of 1.5 %	Total soluble solids (° Bx)	
		Initial	After 35 days
Conventional CA	20	12.43± 0.93	13.07 ± 0.31
Rapid CA	<1	12.43 ± 0.93	12.60 ± 0.20

The LSD value is 1.28 °Bx at 0.05 level of significance.

Table 4 Effect of rate of O_2 pulldown on ascorbic acid content of apples

Storage type	Days to achieve O_2 concentration of 1.5 %	Ascorbic acid (mg/100 mL juice)	
		Initial	After 35 days
Conventional CA	20	6.67 ± 0.81	5.27 ± 0.15
Rapid CA	<1	6.67 ± 0.81	5.87 ± 0.32

The LSD value is 1.14 mg/100 mL of juice at 0.05 level of significance.

Table 5 Effect of rate of O_2 pulldown on weight loss of apples

Storage type	Days to achieve O_2 concentration of 1.5 %	Weight loss (%)	
		Initial	After 35 days
Conventional CA	20	0	0.90 ± 0.08
Rapid CA	<1	0	0.58 ± 0.02

The LSD value is 0.08% at 0.05 level of significance.

CA storage. This fall in ascorbic acid content during storage can be attributed to enzymatic oxidation of L. ascorbic acid to dehydro ascorbic acid. Overall, the beneficial effects of rapid CA might be due to the prompt suppression of fruit respiration rate of apple, which causes immediate depression of metabolic changes, and the associated ripening changes, such as ethylene production and cell wall metabolism.

Conclusions

In slow cooling procedure, the loss of weight, titratable acidity, ascorbic acid and flesh firmness and increase of total soluble solids were significant during the cooldown time i.e. first 14 days and after that the losses were much less. Reducing the cooldown time from 14 days to 7 days as in medium cooling, helped to lower the quality losses of apple. In rapid cooling obtained through LN_2 flushing, the loss in weight, titratable acidity and ascorbic acid did not occur at all during the cooling process and on 35 days after storage they were found to be much higher than those for medium and slow cooled apples. It was also found that majority of the changes in quality of apple were occurred during the O_2 pulldown in CA storage. This suggests that the rapid CA establishment is required if the flesh firmness, weight loss, titratable acidity, total soluble solids, and ascorbic acid content are to be retained.

References

ASHRAE Handbook. 1990. Refrigeration Systems and Applications, American Society of Heating Refrigeration, and Air-conditioning Engineers. Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329.

Bartsch, J. A. 1986. Creating a low oxygen atmosphere with liquid nitrogen. Agricultural Engineering Facts, EF-9. Cooperative Extension, Cornell University, Ithaca, NY.

Bartsch, J. A. and G. D. Blanpied. 1990. Refrigeration and Controlled Atmosphere Storage for Horticultural Crops. Northeast Regional Agricultural Engineering Service Bulletin, Cornell University, Ithaca, NY.

Bohling, H. and M. L. Hellickson. 1998. Physiological responses of red delicious apples during controlled atmosphere storage. Trans. of the ASAE, 41(3): 675-678.

Celis, J. E. and B. C. Stenning. 1995. Design and development of a small container for controlled atmosphere storage. Agricultural Mechanization in Asia, Africa and Latin America, 26(1):37-40.

Chu, C. L. 1997. Starch-iodine test for determining maturity and harvest dates of Empire, Idared and Spartan apples. Horticultural Research Institute of Ontario, Ontario Factsheet, Order No. 88-090. (http://www.gov.on.ca/OMAFRA/english/crops/facts/88-090.htm)

Eksteen, G. J. and A. B. Truter. 1987. Control atmosphere storage of deciduous fruits in South Africa, International J. of Refrigeration, 10(1):14-17.

Hagger, P. E., D. S. Lee and K. L. Yam. 1992. Application of an enzyme kinetic based respiration model to closed system experiments for fresh produce. J. of Food Process Engineering, 15:143-157.

Kader, A. A. 1980. Prevention of ripening in fruits by use of controlled atmosphere storage, Food Technology, 34(3):51-54.

Kays, S. J. 1991. Metabolic processes in harvested products - respiration. In: Post Harvest Physiology of Perishable Plant Products. Van Nostrand Reinhold Publication, New York.

Kupferman, E. 1991. European apple warehouse practices. Tree Fruit Postharvest Journal, 2(3):3-15.

Kupferman, E. 1997. Observations on storage regimes observations for apples and pears. Tree Fruit Postharvest Journal, 8(3):3-5.

Lau, O. L. 1985. Storage factors influencing the quality of apples. Post Harvest Pomology Newsletter, 3(1).

Metlitskii, L. V., E. G. Sal'kova, N. L. Volkind, V. I. Bondarev and V. Y_A. Yanyuk. 1983. Controlled Atmosphere Storage of Fruits. The Amerind Publishing Co. Pvt. Ltd., New Delhi, India.

Mohsenin, N. N. 1970. Physical Properties of Plant and Animal Materials. Vol. I. Gordon and Breach Sci Pub., New York, USA.

Nayital, R. K., S. K. Chopra and Y. P. Sharma. 1990. Effect of post harvest application of calcium chloride, fungicide and wax emulsion on the storage behavior of apple cv. red delicious. Indian Food Packer, 44(3):31-38.

Peterson, S. J., W. J. Lipton and M. Uota. 1989. Methods for premixing gases in pressurized cylinders for use in controlled atmosphere experiments. Hort Science, 24(2):328-331.

Ranganna, S. 1986. Manual of Analysis of Fruits and

Vegetable Products. Tata McGrow Pub. Co., New Delhi, India.

Rocha, A. M. C. N. and A. M. M. B. De Morais, 2000. Effects of controlled atmosphere on quality of minimally processed apple (cv. Jonagored). J. of Food Processing and Preservation, 24, 435-451.

Ryall, A. L. and W. T. Pentzer. 1982. Handling, Transportation and Storage of Fruits and Vegetables, 2nd Edition Volume II, The AVI Publishing Company, Inc., Westport, Connecticut.

Waelti, H. 1994. Energy conservation in CA storages-Program 101, FY- Briefing Report, Cooperative Extension, Department of Biological Systems Engineering, Washington State University. (http://www.bsyse.wsu.edu/extension/CA.html)

Watkins, C. and R. David. 1997. Cornell fruit handling and storage newsletter. Department of Fruit and Vegetable Science, Cornell University, Ithaca, New York.