Agri. & Biosys. Eng. Vol. 4(2):58-65(2003)

Study on Cooling Characteristics of the Tunnel Type Pressure Pre-Cooling System

W. O. Lee, H. S. Yun, K. W. Lee, H. Jeong, K. H. Cho, Y. K. Cho, J. H. Lee

Abstract: An understanding of the cooling requirements of horticultural commodities begins with adequate knowledge of their biological responses. All fresh horticultural products are living organisms, carrying on the many biological processes that are essential to the maintenance of life. The pre-cooling is essential technique for the construction of cold chain system, which is necessary to maintain marketing quality of fresh produces during the transportation and distribution. The purpose of this study is to develop the pressure cooling tunnel using conveyer for the reduction of labor and improvement of pre-cooling efficiency. Performance of developed facility was tested for the strawberries, tomatoes and Chinese cabbages. Cooling ratio as a result of pre-cooling efficiency was 1.57, 1.56 and 1.32 for strawberries, tomatoes, and Chinese cabbages respectively. Cooling ratio decreased with increasing the distance of heat conduction from surface to center. The cooling ratio of Chinese cabbages was lower than that of fruit because of its head and leaf. In aspect of cooling uniformity, there was no significant difference of final temperature among inlet, outlet and middle layers of cold air in fresh produces. After pre-cooling treatment, quality changes were measured for the weight loss, Vit. C content, and titratable acidity. The quality of pre-cooling treatment was better than that of non-treatment and was kept on well during long-term storage.

Keywords: Pressure Pre-cooling, Low Temperature, Tunnel Type, Precooling

Introduction

Differently from processed foodstuffs, fresh horticultural products such as vegetables and fruits tend to lose their original freshness under the influence of ceaseless physiological action in them even after crop, which leads to lower quality than before. Fresh horticultural products are likely to get rotten because of high moisture content and physiological activity, and have lower freshness, even though they are not rotten. Thus, it is essential that fresh horticultural products should be kept fresh in order to supply farm products as fresh as possible for consumers and help to enhance agricultural industry in the level of quality. Also, overcoming those challenges requires high technologies.

If reaped fresh horticultural products are just stored in cold storage at low temperature without any pre-cooling, the cold storage tends to consume more energy because of its higher cooling load resulting from high temperature of fresh horticultural products in itself. In addition, it may be long time to lower the temperature of fresh horticultural products down to certain level. During this rapid cooling, fresh horticultural products may lose much moisture and nutrients, which leads to lower freshness.

Therefore, the 'pre-cooling process' that can decrease the temperature of fresh horticultural as soon as possible just after harvest is prerequisite to supply quality and freshness. For conventional pressure pre-cooling systems, fresh horticultural products have been moved into pre-cooler and cold storage respectively just after pre-cooling by means of forklift or manpower. A series of storage processes like this may cause dew condensation on the surface of fresh horticultural products as exposed to normal temperature and involve mildew or saprogenic bacteria as well, resulting in easy softening of fresh horticultural products, which means rotten vegetables and fruits. Moreover, in case of using forklift for storage, pre-cooling room may require additional space for driving forklift besides its own space to collect reaped fresh horticultura products. It causes larger storage capacity and pre-cooler load as well. Thus, total cooling efficiency becomes lower than expected.

In order to solve disadvantages of conventional pressure pre-cooling system, this study was aimed to develop new

The authors are **Won Og Lee**, Junior Researcher, **Hong Sun Yun**, Senior Researcher, **Kyeong Hwan Lee**, Junior Researcher, Hun Chung, Junior Researcher, **Kwang Hwan Cho**, Senior Researcher, **Yeoung Kil Cho**, General Director, National Institute of Agricultural Engineering, RDA. Suwon, KOREA. **Chong Ho Lee**, Professor, Division of Bioresource Systems Engineering Chonbuk National University, Jeonju, KOREA. **Corresponding author:** Won Og Lee, Junior researcher, National Institute of Agricultural Engineering 249 Seodun-dong, Suwon, Kyunggi-Do, 441-100, KOREA; e-mail: lwo2000@rda.go.kr

type pre-cooler that can keep low temperature continuously in connection with cold storage, automate a series of works such as warehousing, pre-cooling and delivery with more convenience, and carry out pre-cooling process effectively in a short time. Furthermore, the study also focused on clarifying the cooling properties of new pre-cooler.

Materials and Methods

1. Design and making of tunnel type pressure pre-cooler

(1) Clarification of design factors in the tunnel type pressure pre-cooler

To clarify the design factors of pre-cooler, cooling load as required for cooling was calculated and the amount of blowing air to cool the heat value as much as cooling load was determined. Based on the amount of blowing air as needed, basic cooling capacity of pre-cooler and the size of pressure blowing fan were determined respectively.

a) Working conditions in design

Working conditions of pre-cooler were designed so that 1.4 tons of strawberry at initial temperature of 25℃ could be cooled down to low temperature of 5℃ within 2 hours. Also, it was assumed that the temperature of open air was 32℃ and relative humidity 60%, based on evaporation temperature of -10℃ and condensation temperature of 45℃.

b) Selection of pre-cooler and air blower

To determine the capacity of pre-cooler and air blower for pre-cooling process, cooling load needed to cool peach down to 5℃ was calculated through categorization into ① heat loss on the wall of pre-cooling storage ② heat from cooling fresh horticultural products ③ heat from respiration of fresh horticultural products ④ heat from pressure blowing fan and so on. By applying safety ratio at 20%, total capacity of pre-cooler was determined.

(2) Making of tunnel type pressure pre-cooler

a) Structure and specification of tunnel type pressure pre-cooler

The tunnel-type pressure pre-cooling system made by design as described above consists of the following components: *Inlet conveyor* to automatically correct the posture of palettes that contain a pile of packaging boxes and put the palettes into pre-cooling room; *Warehousing and delivery door* that open and close by sliding up and down in front and rear of pre-cooling room; *Feeding conveyor* that moves palettes from pre-cooling room to appropriate position; *Pressure blowing fan and Fabric cover* for reliable pressure cooling; *Cooler* to lower the temperature of pre-cooling room; *Control system* to automatically adjust the working of pre-cooler;

Table 1 Specifications of the refrigerator used in this study

Refrigerating Load	22,764 kcal/h	
Blower	Air flow rate	60 CMM
	Static pressure	30 mmAq
	Type	Speed control type
Refrigerator	Compressor	3 Hp×2 units
	Condenser	11,500 kcal/hr×2 units
		Temperature : 45℃
	Unit cooler	11,500 kcal/hr×2 units
		Evaporating temperature : -5～-10℃

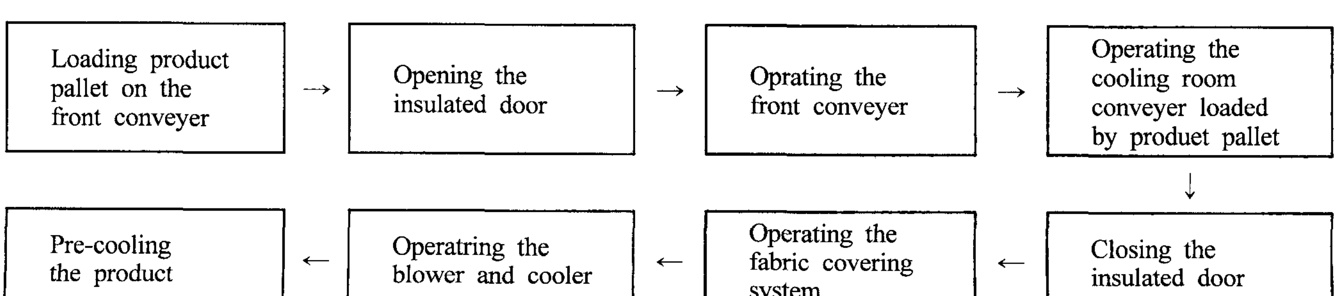

Fig. 1 Operation flow of tunnel type pressure pre-cooling system.

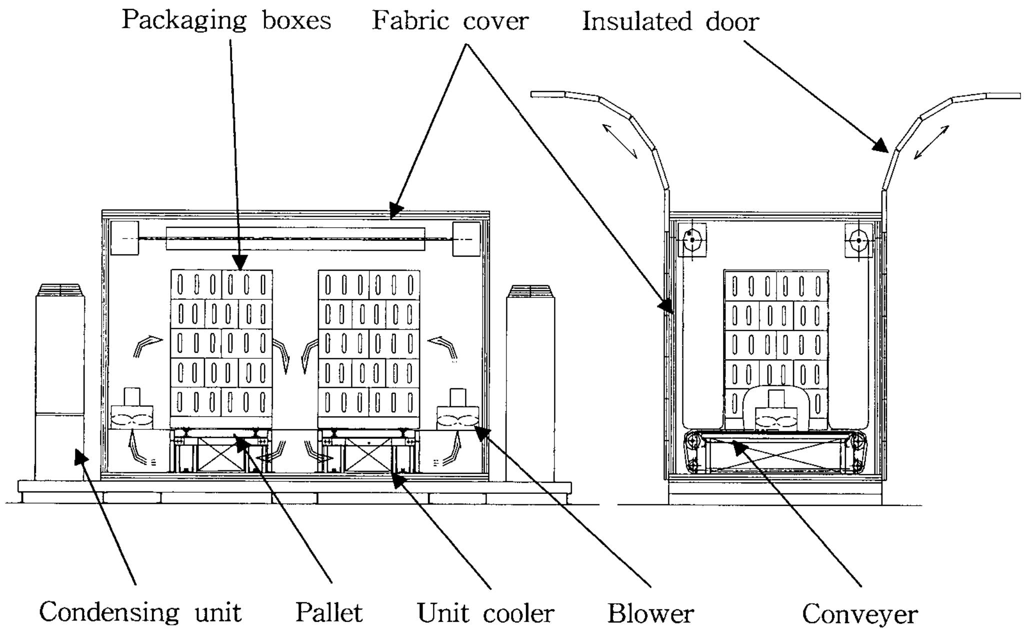

Fig. 2 Schematic diagram of the tunnel type pressure pre-cooling system.

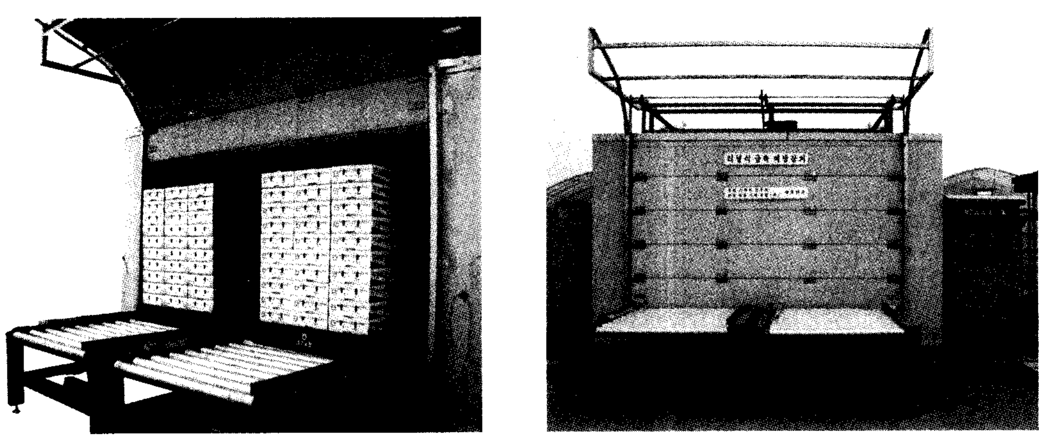

Fig. 3 Configration of tunnel type pressure pre-cooling system.

and so on. The procedure of cooling works for tunnel type pressure pre-cooler was illustrated in Fig. 1. For the structure and specification in more detail, see Figs. 2, 3

b) Characteristics of tunnel type pressure pre-cooler

Tunnel type pressure pre-cooler has major characteristics as follows: ① Puts fresh horticultural in palette sequentially into pre-cooling room ② Puts palettes with fresh horticultural products automatically into pre-cooling room for more convenience during pre-cooling works ③ The pre-cooler linked with cold storage can make you keep controlling the quality of fresh horticultural products under low temperature continuously, which helps to prevent the quality of pre-cooled fresh horticultural products from deteriorating due to dew condensation as often shown under exposure to open air. ④ Easily installed in connection with selective packaging or cold storaging facilities to improve the space utility of processing facilities in producing location.

2. Performance test of tunnel type pressure pre-cooler

(1) Specimens for testing

Strawberry, tomato and chinese cabbage were used to evaluate the cooling performance of tunnel type pressure pre-cooling system. Using strawberry from Buyeo (Chungnam province), tomato from Gongju (Chungnam province) and chinese cabbage from Pyeongchang (Gangwon province), on-site cooling tests were performed in those producing locations, respectively. Moreover, the variations of quality depending upon the distributing conditions of those crops were compared with one another and analyzed.

(2) Test methods

a) Pre-cooling test of tunnel type pre-cooler for each crop

Pressure blowing fan was controlled so that the amount required for cooling each crop may reach 0.04 m^3/m per weight (kg) of specimen. The temperature of cooling air was kept at 3℃ for strawberry and chinese cabbage and 6℃ for tomato, respectively. Table 2 shows the type of packaging box used for cooling test with each crop, how to pile up the box, the amount of specimen used for test.

Table 2 Packing and loading conditions of the various fresh produces tested for pre-cooling

b) Measurement of cooling temperature

With the aforementioned specimens piled up in palette, cooling temperature for each crop was measured at intervals of 5 minutes by means of temperature sensor (T-type thermocouple) installed in specimens on each layer such as cool air inlet, intermediate layer and cool air outlet respectively, using multi-point temperature recorder (DR242, Yokogawa, Japan). Temperature sensor was installed in the core (for fruits) and in the center of lower part (for chinese cabbage) respectively. The gap between the surface of crops and temperature sensor was sealed up with silicone to prevent air permeation.

c) Test for quality change during distribution after pre-cooling

For the comparison of pre-cooling effects on each crop, any quality change in each crop was investigated under three conditions such as distribution at low temperature after pre-cooling, distribution at low temperature without pre-cooling and distribution at normal temperature without pre-cooling. On the other hand, the indices for evaluating quality included the followings: firmness, chroma L value and weight loss rate (for strawberry); Titrated acid, ascorbic acid and chroma a value (for tomato); cutting force of stem (for chinese cabbage).

Results and Discussions

1. Cooling performance of tunnel type pressure pre-cooler

The cooling rate of crops in the core of each layer within packaging box was measured to determine the cooling performance of tunnel type pressure pre-cooler. According to Yun's report (Yun, 1997) saying that cooling rate increased with more amount of blowing air required for cooling, but such increase rate slowed down little by little till it stayed at certain level with blowing air beyond 0.04 m^3/min · kg, the cooling experiment was carried on by keeping blowing air at 0.04 m^3/min · kg. Result of cooling rates for each crop were shown in Table 3. It was found that there was lower cooling rate with longer heat traveling distance from outer surface to core of pre-cooled fresh horticultural products, and the cooling rate of chinese cabbage with many bulbs and leaves reached lower level. The time to cool the temperature of reaped fresh horticultural products down to low level for pre-cooling varied depending on the type of crop, but it usually averaged 2~3 hours.

In addition, the temperature of pre-cooled fresh horti-

Table 2 Packing and loading conditions of the various fresh produces tested for pre-cooling

Items	Packing box			Box loading method (row×column×layer)	Total weight (kg)
	Size (mm)	Weight	Vent hole		
Strawberry	540×360×90	6 kg	Number 6ea ratio 5.0%	3×2×2	960
Tomato	440×330×185	10 kg	Number 6ea ratio 5.0%	2×4×6	960
Chinese cabbage	480×320×225	8 kg	Number 6ea ratio 5.0%	3×2×6	576

Table 3 The trends of cooling rate in the various fresh produces

Items	Temperature(℃)		Cooling time (hr)	Cooling velocity (℃/hr)	Cooling rate (1/hr)
	Initial	Final			
Strawberry	23.3	4.2	1.8	10.6	1.57
Tomato	31.3	10.0	2.3	9.3	1.56
Chinese cabbage	20.2	4.4	2.6	6.1	1.32

cultural on each layer such as cool air inlet, intermediate layer and cool air outlet was respectively measured to find out the cooling uniformity of pre-cooled fresh horticultural products between packaging boxes piled up on every palette. The results were illustrated in Figs. 4, 5 and 6. Here, in terms of cooling uniformity for each crop, tomato and chinese cabbage showed little or no differences in the

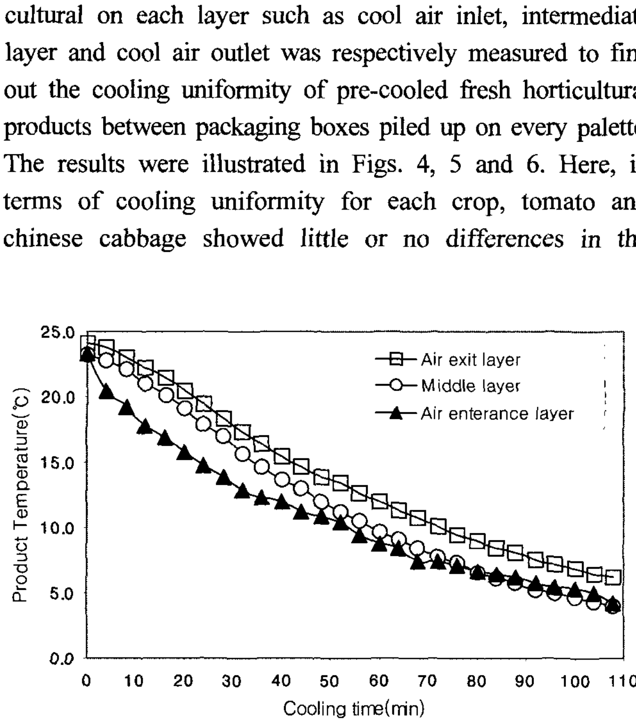

Fig. 4 Temperature change of packaged strawberry at three different layers in box.

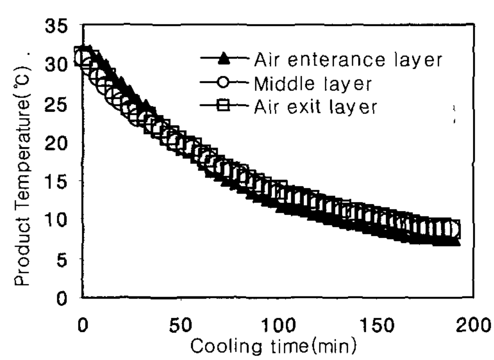

Fig. 5 Temperature change of packaged tomato at three different layers in box.

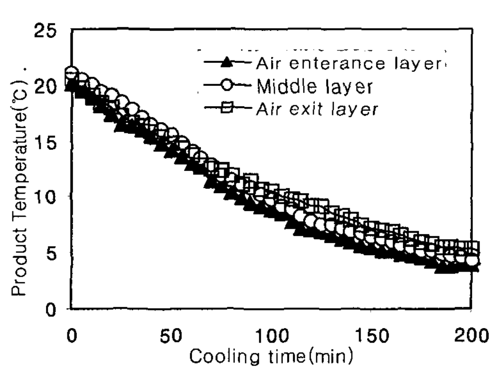

Fig. 6 Temperature change of packaged chinese cabbage at three different layers in box.

temperature of fresh horticultural products between on the layer of cool air inlet and outlet. However, the cooling rate of strawberry was faster on the layer of cool air inlet, while slower on the outlet. It corresponds to the Equation of Ramsin & Ergun showing that shorter gap between layers of piled fresh horticultural products in packaging box and higher blowing velocity would lead to higher blowing resistance (Chau et al., 1985; Ergun, 1952). In particular, it is estimated that strawberry with less gap than other fresh horticultural products shows deviation in its temperature between the layer of inlet and outlet because of high blowing resistance.

2. Change of quality shown in each pre-cooled crop

(1) Change of quality in strawberry

The variation of firmness, chroma 'L' value and weight loss rate were measured for three types of strawberry: Pre-cooled strawberry in cold storage, strawberry in cold storage without pre-cooling and strawberry in storage at normal temperature. As the storage temperature becomes higher and the storage period becomes longer, the firmness of strawberry generally tended to be lower as shown in Fig. 7. Pre-cooled strawberry showed little variations in firmness during cold storage, while strawberry in cold storage without pre-cooling showed lower firmness little by little than pre-cooled one. The firmness of strawberry in storage at normal temperature decreased rapidly in 2 days. In general, it is known that lower firmness of strawberry shown at normal temperature or higher is possibly attributed to increasing soluble pectin within cell wall of strawberry directly due to lower content of moisture at high temperature (Choi et al., 1983; Kim et al., 1996; Lurie et al., 1986). As shown in Fig. 8, the rind chroma of strawberry tended to be higher at lower storage temperature, while lower during longer storage period. Pre-cooled strawberry in cold storage showed little or no variation in the color of its rind till the 4th day, while non-pre-cooled strawberry showed rapidly changing chroma L value during storage period.

As shown in Fig. 9, weight variation in strawberry during storage period showed almost same tendencies till the 2nd day, whether the strawberry sample was the pre-cooled one or the non-pre-cooled one in cold storage. It is possibly attributed to weight loss in the process of pre-cooling. Notably, pre-cooled sample showed 3% in weight loss rate till the 6th day, while non-pre-cooled specimen in cold storage showed 5% or higher in weight loss rate from the 6th day (from the 4th day for the specimen in storage at normal temperature), which was an obstacle to maintain commercial value. Leser & Burton reported that vegetables likely had lower commercial value at moisture loss beyond 5%, because the weight loss during storage has more or less relationship with lower quality. Also it was reported that melon would undergo various physical degradations at moisture loss beyond 5.7% (Laster et al., 1986; Lurie et al., 1986). Likewise, in this experiment, non-pre-cooled specimen in cold storage lost 5% or more of its original weight from the 6th day of

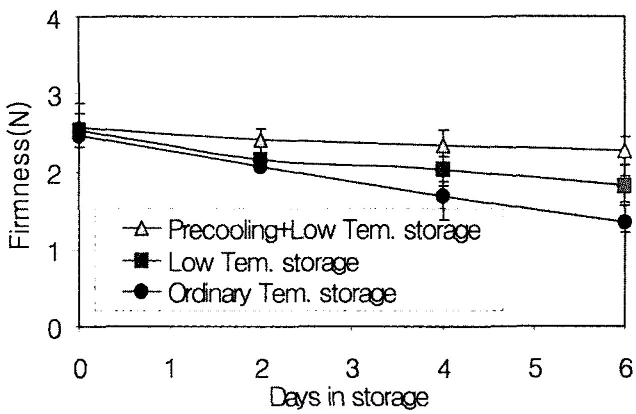

Fig. 7 Change in firmness of strawberry according to various storage methods.

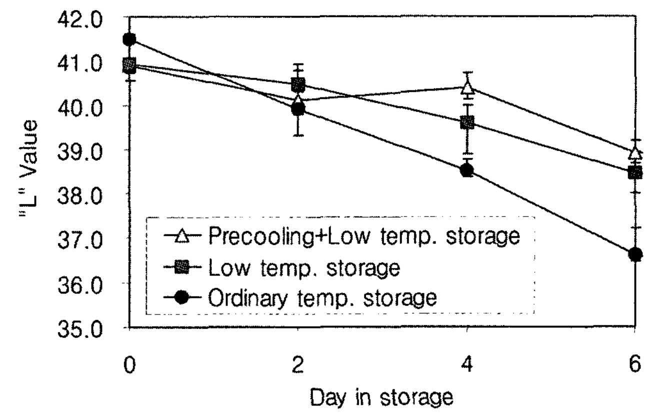

Fig. 8 Change in the "L" value of skin color of strawberry according to various storage methods.

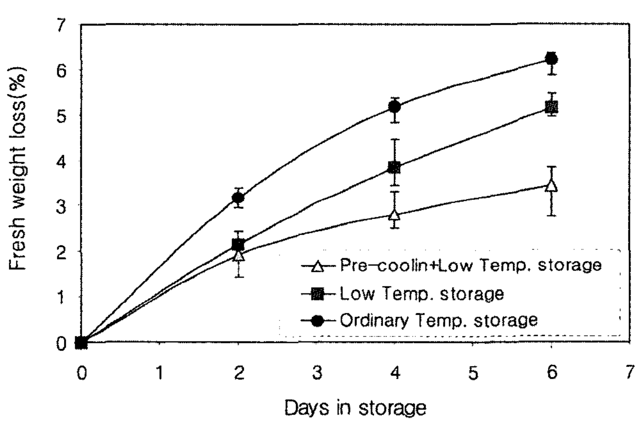

Fig. 9 Change in fresh weight of strawberry according to various storage methods.

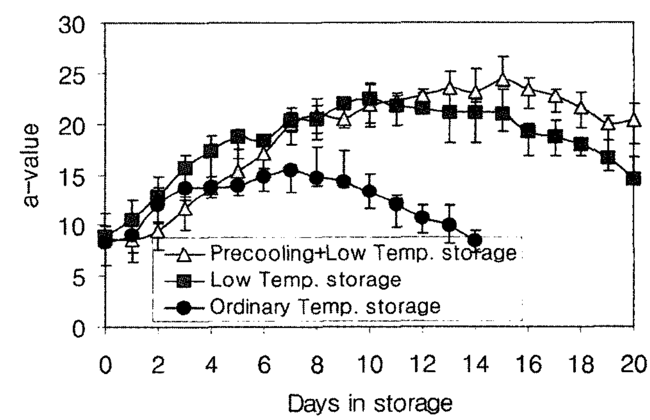

Fig. 10 Change in the "a" value of skin color of tomato according to various storage methods.

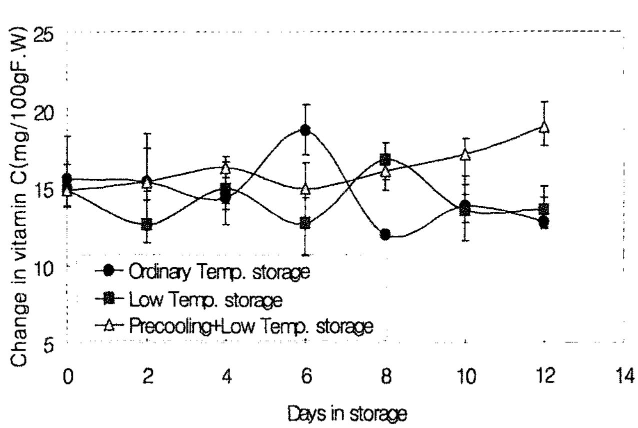

Fig. 11 Change in vitamin C of tomato according to various storage methods.

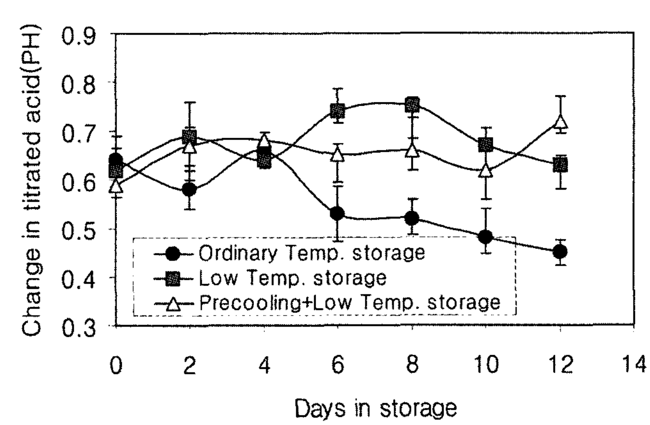

Fig. 12 Change in titrated acid of tomato according to various storage methods.

storage, while specimen in storage at normal temperature did so from the 4th day. Such weight loss was regarded as little or no commercial value as fresh horticultural products.

(2) Change of quality in tomato

As a result of measuring the rind chroma of tomato, non-pre-cooled sample in storage at normal temperature and in cold storage showed the highest chroma 'a' value at the 7th and 12th day of storage respectively, as shown in Fig. 10. Afterward, the rind of specimens discolored like dark red. On the other hand, the pre-cooled sample in cold storage showed the highest chroma 'a' value at the 18th day, which means apparently sustainable freshness for longer time than other ones. It has been reported that the change of chroma is useful as an index showing maturity in terms of tomato (Kader, 1985; Kays, 1991). Therefore, it is estimated that the changing chroma of tomato in the course of pre-cooling has close relationship with the amount of ethylene generated as one of growth hormones for fruits. For pre-cooled tomato sample, rapid cooling helped suppress further ripening because of lower amount of ethylene generated, while non-pre-cooled sample in storage at normal temperature and in cold storage showed that increasing amount of initial ethylene possibly facilitated the change of chroma.

Moreover, non-pre-cooled specimen in storage at normal temperature showed the highest content of ascorbic acid (19.15 mg/100 gFW) in 6 days after storage, while non-pre-cooled specimen in cold storage did so (16.79 mg/100 gFW) in 8 days. Afterward, the content of ascorbic acid rapidly decreased for two sample groups as described above. On the other hand, pre-cooled specimen in cold storage showed gradually increasing content of ascorbic acid and reached the highest in 12 days after storage (See Fig. 11). For ascorbic acid, its level tends to increase gradually in the course of ripening and decrease rapidly after full maturity (Lyon, 1973; Morris et al., 1977; Robinson et al., 1975; Ryall et al., 1972). It may stem from the velocity of further ripening in tomato. It was apparent that pre-cooling helped to control the ripening of tomato, while the content of ascorbic acid for the sample in storage at normal temperature and non-pre-cooled one in cold storage reached the highest level even in a short period, because such sample underwent normal ripening.

As a result of experiments in this study, it was found that the titrated acid of tomato increased till its full ripening and decreased afterward, and this result corresponds to the report. saying that the acidity of matured green vegetables and fruits during storage tended to decrease after full ripening (Winsor et al., 1962). As shown in Fig. 12, the acidity of pre-cooled specimen in cold storage increases gradually till the 12th day after storage, while the acidity of non-pre-cooled specimen in storage at normal temperature and the one in cold storage reached the highest level in 5 days and 7 days respectively. Thus, it is concluded that pre-cooling is very helpful to keep tomato fresh for longer period than other treatments.

(3) Change of quality in Chinese cabbage

After applying cutting force to leaf and stem of cabbage, the typical force-distance curves were obtained as shown in Fig. 13. The figure shows characteristic 3 peaks: A indicates a peak (1st cutting force) upon cutting inner husk of cabbage stem, B indicates a peak (2nd cutting force) upon cutting the section in vascular bundle of cabbage stem and C indicates the force (3rd cutting force) required for cutting outer husk of cabbage (Lee et al., 1988; Lee et al., 1988). As shown in Fig. 13, more cutting force is required for cutting vascular bundle of cabbage rather than cutting its outer husk. It represents characteristic curves in cutting test. These curves also show that the peak of outer husk increases as whole cabbage is withered after harvest. This result corresponds to the results reported by Bourne (Bourne, 1968).

As shown in Figs. 14, 15 and 16, non-pre-cooled sample in storage at normal temperature showed rapidly increasing cutting force over its outer husk in the course of time. Compared to pre-cooled specimen in cold storage, non-pre-cooled one in cold storage showed higher cutting force over its outer husk. It is estimated that these results are possibly attributed to geometrical transformation by a stack of cell walls mainly due to higher temperature and evaporated moisture in the course of storage period. Thus, it is recommended that chinese cabbage should be pre-cooled for distribution in market so as to keep it fresh.

Conclusions

In this study, a tunnel type pressure pre-cooler was developed in order to automate pre-cooling processes for reaped green fruits and vegetables and enhance the cooling efficiency. For better pre-cooling efficiency through less manpower and low temperature maintenance by facilitating mechanical connection between working processes before and after pre-cooling, the pre-cooler was designed and made to automate whole processes from warehousing, delivery and pre-cooling for fresh horticultural products piled on palettes via conveyor.

As a result of pre-cooling efficiency, cooling ratio presented that 1.57 for strawberries, 1.56 for tomatoes, 1.43 as peach and 1.32 for Chinese cabbage. Cooling ratio decreases with increasing the distance of heat conduction from surface to center. The cooling ratio of Chinese cabbage was lower than that of fruit because of its head and leaf. In aspect of cooling uniformity, there was no significant difference of final temperature among inlet layer, outlet layer and middle layer of cold air in fresh produces

For the test of quality change in strawberry during storage period, non-pre-cooled sample lost 5% or more of its original weight in 4 days after storage, which means little or no commercial value, while pre-cooled sample lost max. about 3% of its original weight till the 6th day after storage. For the test of acidity change in tomato, the acidity of pre-cooled sample gradually increased till the 12th day after storage, while the acidity of non-pre-cooled one reached the highest level in 7 day after storage. Thus, it is concluded that pre-cooling is very helpful for keeping tomato fresh for longer time. Finally, for the test of cutting force over chinese cabbage, it was found that the cutting force over outer husk of pre-cooled cabbage stem was lower (3 kg/cm^2) than that of non-pre-cooled one (5.8 kg/cm^2) in 5 days after storage. Thus, it is concluded that pre-cooled cabbage may have its fresh stem for longer time than anything else.

References

H. S. Yun, and K. K. Park. 1997. Cooling characteristics of fruits and vegetables for pressure pre-cooling. Kor. J. Postharvest Sci. Technol. Agri. Products. 4(3): 237-243.

Chau, K. V., J. J. Gaffney, G. A. Baird and G. A. Church. 1985. Resistance to air flow of oranges in bulk and in cartons. Transactions of the ASAE. 28(6):2083-2088.

Ergun, S. 1952. Fluid Flow through packed columns. Chem. Engg. Progr. 48(2):89-94.

Choi, S. J., Y. C. Kim and K. W. Park. 1983. Changes in pectic substance during the storage of tomato fruits at varied temperature. J. Kor. Soc. Hort. Sci. 24(2):118-123.

Kim, Y. B., K. Yasutaka, I. Akitsugu and N. Reinosuke. 1996. Effect of storage temperature on keeping quality of tomato and strawberry fruits. J. Kor. Soc. Hort. Sci. 37(4):526-532.

Lurie, S. B. and S. Ben-Yehoshur. 1986. Effects of water stress and degree of ripeness on rate of senesence of harvested bell pepper fruit. J. Amer. Soc. Hort. Sci. 111(3):880-885.

Laster, G. E. and B. D. Burton. 1986. Relationship of netted muskmelon fruit water loss to postharvest storage life. J. Amer. Soc. Hort. Sci. 111(5):727-731.

Kader, A. A. 1985. Ethylene-induced senescence and physiological disorders in harvested horticultural crops. HortScience 20(1):54-57.

Kays, S. J. 1991. Postharvest physiology of perishable plant products. pp. 532. Van Nostrand Reinhold Co. New York.

Lyon, J. M. 1973. Chilling injury in plants. Annu. Rev. Plant Physiol. 24:445.

Morris, L. L. and A. A. Farder. 1977. Phsiological disorders of certain vegetables in relation to modified atmosphere. Proc. 2nd National Controlled Atomosphere Conf., Mich. State Univ. Hort. Rep. 28:142.

Robinson, J. E., K. M. Browne and W. G. Burton. 1975. Storage characteristics of some vegetables and soft fruits. Ann. Appl. Biol. 81:399-408.

Ryall, A. L. and W. J. Lipton. 1972. Handling transportatiom and storage of fruits and vegetables, Vol. 1, Vegetables and Melons, AVI Publishing, Wesport, Conn. 473.

Winsor, G. W., J. N. Davies and D. M. Massey. 1962. Composition of tomato fruit. III. Juices from whole fruit and locales at different stages of ripeness. J. Sci. Food Agri. 13:108.

Lee, C. H., I. J. Hwang and Jeong-Kyo Kim. 1988. Macro and microstructure of Chinese cabbage leaves and their texture measureements. Kor. J. Food Sci. Technol. 20(6):742.

Lee, C. H. and I. J. Hwang. 1988. Comparison of cutting and compression tests for the texture measurement of Chinese cabbage leaves. Kor. J. Food Sci. Technol. 20 (6):749-754.

Bourne, M. C. 1968. Texture Profile of ripening pears. J. Food Sci. 33:223.