POST-HARVEST QUALITY MAINTENANCE OF VEGETABLES

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ABSTRACT

Post-harvest technology of vegetables from harvest to the time of consumption has made rapid progress in the past two decades in Japan, including careful harvesting and sorting, strict standardization, development of appropriate packing materials, mechanized pre-cooling facilities, refrigerated system, and neat display methods.

Since vegetables remain as living plants after harvest, biological phenomena are operating during the distribution, i. e. respiration, transpiration leading to water loss, ethylene production, senescence of leafy vegetables, ripening of fruit vegetables, growth and development. As the biological changes are associated with important chemical changes which are closely related to the quality of the produce, the effect of biological phenomena should be reduced as much as possible.

In order to maintain the freshness of vegetables, the following post-harvest environmental factors need to be considered : 1) handling method, 2) temperature, 3) relative humidity, and 4) atmospheric conditions (O_2, CO_2 and N_2 proportions).

Post-harvest technology in Japan

1 Year-round production and supply of vegetables

Although Japan is a country belonging to the temperate zone, her climate varies from North to South and from mountains to plains.

Year-round supplying system of vegetables established in recent years has been supported by the following technologies.

1) Use of cold-resistant and heat-tolerant cultivars.
2) Production depending on climate : summer production in highlands and high latitude areas and winter production in southern warm coastal areas.
3) Production under protected cultivation by use of glasshouse, plastic house, row cover and mulching.
4) Advanced transportation system : packaging, pre-cooling system, refrigerated transportation system and paved roads, etc.

Fig. 1 illustrates how cabbage is evenly supplied in Tokyo central wholesale markets annually. Tokyo central wholesale markets deal with almost the same amount of cabbage every month. The prices, on the other hand, fluctuate markedly with the seasons. In 1986 the cabbage price in winter was 1.0 dollar/kg (\$ 1=¥ 130), while in summer it was 0.35 dollar/kg, or less than one third of that in winter (in 1987 however the cabbage price was extremely high in summer). The reasons of those fluctuations remain unknown in free marketing system.

Vegetables are transported to Tokyo, the capital of Japan, from various producing areas in different seasons. Table 1 shows that between January and March, Aichi prefecture supplied the largest amounts of cabbage, while between April and June it was Chiba prefecture, and between July and September Gunma prefecture.

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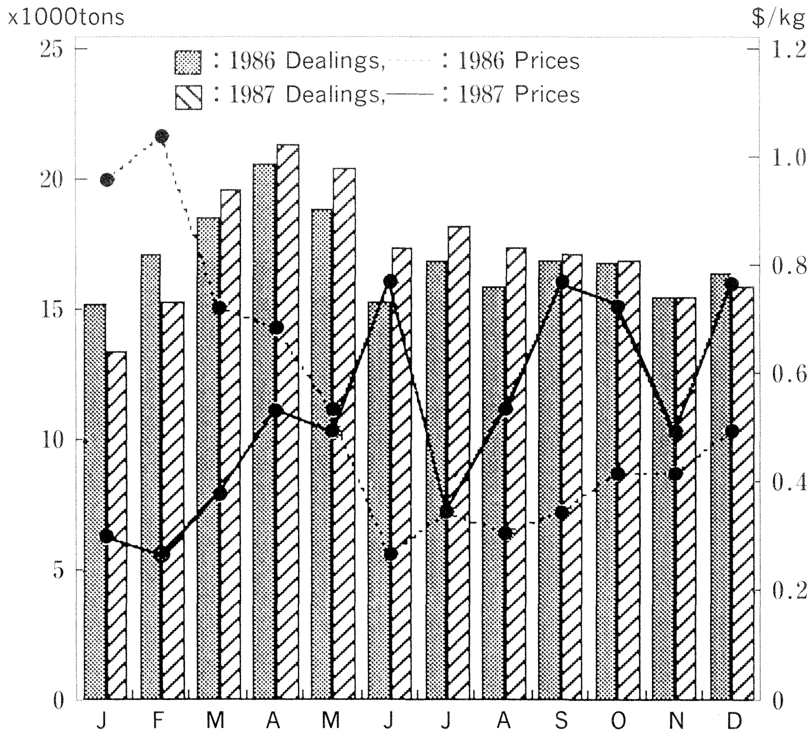


Fig. 1 Dealings and prices of cabbage in Tokyo central whole-sale markets (Janurary-December, 1986 and 1987)

Table 1 Total amount of vegetable dealings in relation to seasons and producing areas in Tokyo wholesale markest (cabbage, 1987)

January-March			April-June			July-September			October-December		
Prefecture	Dealings (ton)	%	Prefecture	Dealings (ton)	%	Prefecture	Dealings (ton)	%	Prefecture	Dealings (ton)	%
Aichi	26,622	52	Chiba	17,377	34	Gunma	38,200	82	Chiba	14,607	31
Kanagawa	9,381	18	Kanagawa	12,553	25	Tokyo	1,691	4	Aichi	10,722	23
Chiba	7,021	14	Aichi	6,469	13	Hokkaido	1,554	3	Tokyo	7,680	16
Wakayama	3,342	7	Tokyo	6,281	12	Nagano	1,267	3	Gunma	6,765	14
Shizuoka	2,043	4	Saitama	3,115	6	Chiba	862	2	Kanagawa	1,927	4
Others	2,690	5	Others	5,145	10	Others	2,847	6	Others	5,435	12
Total	51,099	100	Total	50,940	100	Total	46,411	100	Total	47,136	100

2 Shipment standards for vegetables

The Ministry of Agriculture, Forestry and Fisheries of Japan has established shipment standards for major vegetables (23 vegetables until now). Marketing system adopting the shipment standards has contributed to the maintenance of a high and uniform quality. The shipment standards of cabbage are presented in Table 2. The standards control quality, size, weight, number of cabbages in a box, and packing boxes (materials, size, packing method, indication of contents, etc.).

3 Pre-cooling

By pre-cooling treatment field heat is rapidly removed from fresh vegetables during

Table 2 Shipment standard of cabbage

1. Quality standard
   1) Characteristic shape for cv. and good appearance
   2) Firm and non-cracked head
   3) No flower stalk development
   4) Not rancid
   5) No disease, insect and mechanical jnjuries
   6) Good removal of outer leaves
   7) Good removal of stalk
   8) Clean
2. Size standard

Size	Spring cabbage		Summer-winter cabbage	
	Weight (kg)	No. in a box*	Weight (kg)	No. in a box*
2L	2.0<	8 >	1.9-1.5	8-10
L	2.0-1.5	9-11	1.5-1.3	11-12
M	1.5-0.9	12-16	1.3-1.1	13-14
S	0.9-0.7	17-22	1.1-0.7	15-22

*: Corrugated box for 15 kg cabbage, 48 cm × 32 cm × 31 cm.

or after handling for market shipment. This technology enables to minimize the deterioration occurring during the marketing process. The characteristics of several kinds of pre-cooling methods are indicated in Table 3 (Mitchell, 1985). Room cooling, forced-air cooling, and vacuum cooling are commonly used in Japan. Those facilities have been constructed within the last two decades (Table 4). Forced-air cooling and vacuum cooling methods have become popular recently.

4 Marketing channels

Marketing channels for horticultural products in Japan are illustrated in Fig. 2. A main route of horticultural products from farmers to consumers is as follows : producers → agricultural cooperative association → wholesalers → middleman → retailers → con-

Table 3 Cooling methods and commodities[3)]

Cooling method*	Commodities cooled
Room cooling	All commodities
Forced-air cooling (Pressure cooling)	Fruits, berries, fruit-type vegetables. tubers, cut flowers, cauliflower
Hydrocooling	Stems, leafy vegetables, some fruits and fruit-type vegetables
Package-icing	Roots, stems, some flower-type vegetables, green onions, Brussels sprouts
Vacuum cooling	Leafy vegetables ; some stem and flower-type vegetables
Transit cooling : Mechanical refrigeration	All commodities
Top-icing and channel-icing	Some roots, stems, leafy vegetables, cantaloupes

* For these methods to be effective, cold-storage rooms are needed to store the commodity after cooling.

Table 4 Construction of pre-cooling facilities in Japan (1965-1986)

Year	Room cooling	Forced-air cooling	Vacuum cooling	Hydrocooling
1965	1			
1966				
1967	1			
1968	3			
1969	3			
1970	15			
1971	23			
1972	29			
1973	36		5	
1974	31			
1975	36		1	
1976	38		7	
1977	59		11	
1978	91	7	12	
1979	98	10	12	5
1980	114	18	22	
1981	80	42	27	1
1982	65	47	15	
1983	69	71	9	
1984	81	83	18	
1985	61	75	12	3
1986	75	66	26	1
Total	1009	419	177	10

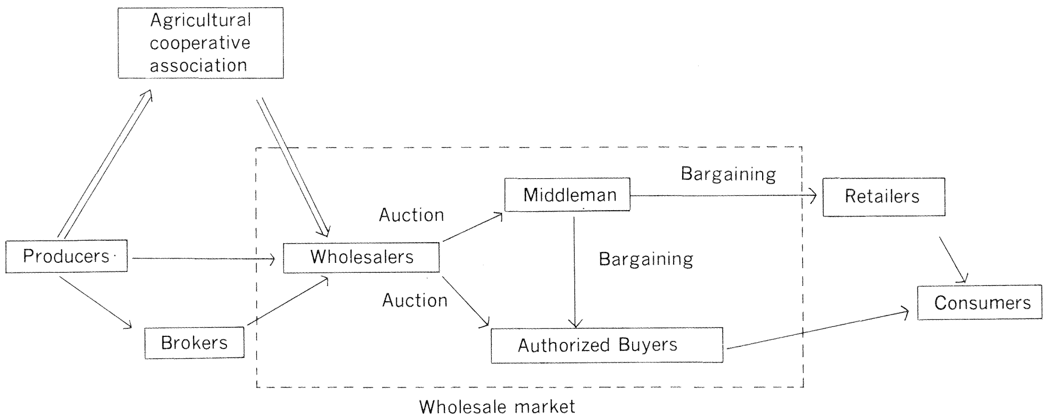


Fig. 2 Marketing channels for horticultural products, livestock and marine products in Japan

sumers. Dotted line indicates the activity in a wholesale market. The route of horticultural products is the same as that of livestock and marine products.

An example of vegetable shipment, broccoli produced in Aichi prefecture, is presented in Fig. 3. Broccoli produced from October to June, is harvested by hand, trimmed, graded, and packed into corrugated boxes according to the shipment standards by farmers. Packages of broccoli are brought to a collection and shipment center, then cooled for 30 min to ca. 5°C with a vacuum cooler, except in winter, and stored temporarily in

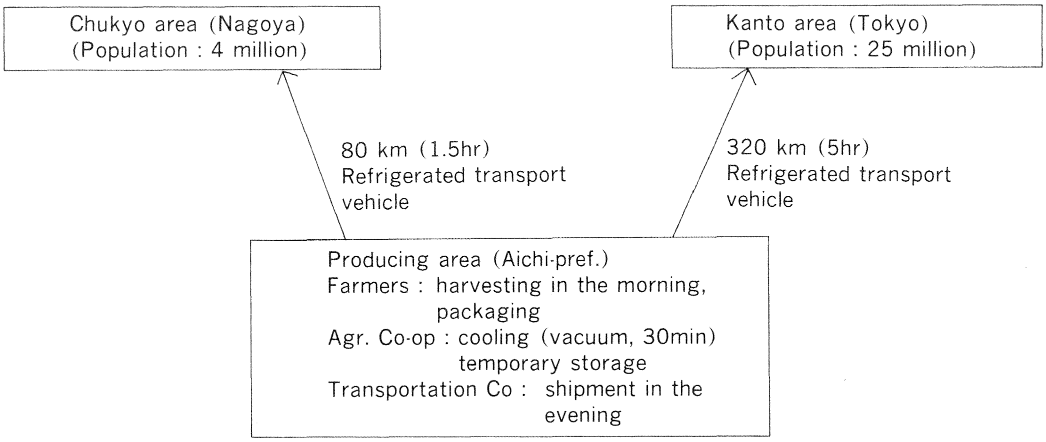


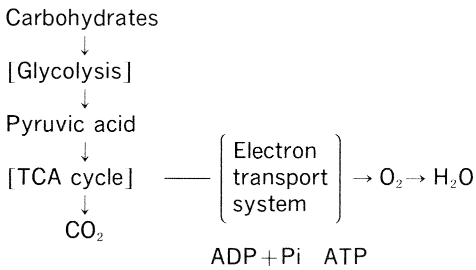
Fig. 3 Shipment of vegetables (ex. broccoli, Atsumi county, Aichi prefecture)

a cold room. The commodities are loaded onto a refrigerated transport vehicle and transported to a wholesale market (90% to Kanto area and 10% to Chukyo area). At a wholesale market vegetables are auctioned early in the morning, transported, and then displayed at a retail market before noon.

Basic post-harvest physiology of vegetables

1 Respiration

Vegetables remain as living plants after harvest and their quality deteriorates depending on the environmental conditions. These highly perishable living organisms consume carbohydrates by respiration. Respiration is a biological oxidation : carbohydrates such as glucose, fructose, sucrose and starch are metabolized to pyruvic acid through glycolysis, and decomposed to carbon dioxide and water through the tricarboxylic acid cycle (Fig. 4). During the metabolism an energy-rich compound, ATP, is synthesized and ATP accounts for about 40% of the total energy produced by oxidation of glucose.



[Overall oxidation and phosphorylation]

$$C_6H_{12}O_6 + 6O_2 + 38ADP + 38H_3PO_4 \rightarrow 6CO_2 + 38ATP + 44H_2O$$

$$\Delta G' = -409{,}000\text{cal}$$

Fig. 4 Respiratory metabolism in plant

Another source of energy is released to the environment as respiration heat, which is the cause of temperature increase of stored vegetables.

Respiration consumes the carbohydrates contained in vegetables (nutritively valuable and sweet materials), decreases their fresh weight and accelerates senescence. Table 5 classified vegetables and fruits according to their respiration rates.

In order to maintain the freshness of vegetables or to store them under good conditions it is necessary, therefore, to reduce respiration and make them live slowly. the most important factor for the reduction of the respiration is the environmental temperature.

2 Transpiration

As the surface of the plant tissues is covered by a relatively hard cuticule layer, water does not permeate through the surface freely. When a vegetable grows in the field, the stroma on the surface secures water loss by transpiration to adjust the plant temperature. However there is no special physiological mechanism in vegetables after harvest.

Water loss by transpiration causes weight loss, deterioration of appearance (wilting and shrivelling) and texture (loss of crispness and juiciness) qualities. Generally 5% of weight loss indicates a clear deterioration in appearance quality.

Transpiration activity is influenced by many factors (horticultural produce characteristics and environments). Produce morphology, tissue properties, ratio of surface to weight, injury and maturity are important produce characteristics. Temperature, relative humidity, air flow rate and atmosphere pressure are also important environmental factors. Packing with plastic films is an effective method to control transpiration by maintaining a high relative humidity and reducing the air flow rate.

3 Biochemical and chemical changes

Ethylene acts as a ripening hormone or an aging hormone. The biosynthetic pathway and regulatory mechanisms have been analyzed by Yang (1985). The rate-limiting steps in ethylene biosynthesis include the conversion from S-adenosylmethionine to 1-aminocyclopropane-1-carboxylic acid (ACC) catalyzed by ACC synthase and the step from ACC to ethylene catalyzed by ethylene-forming enzyme. ACC synthase activity which is usually suppressed is induced by fruit ripening, flower senescence, IAA, physical wounding, chilling injury, drought stress, etc.

Ethylene is practically used as a ripening hormone for fruits. In contrast it hastens

Table 5 Classification of horticultural commodities according to their respiration rates

Class	Range at 5°C (41°F) (mg CO_2/kg/hr)[1)]	Commodities
Very low	< 5	Nuts, dates, dried fruits and vegetables
Low	5 -10	Apple, citrus, grape, kiwifruit, garlic, onion, potato (mature), sweet potato
Moderate	10-20	Apricot, banana, cherry, peach, nectarine, pear, plum, fig (fresh), cabbage, carrot, lettuce, pepper, tomato, potato (immature)
High	20-40	Strawberry, blackberry, raspberry, cauliflower, lima bean, avocado
Very high	40-60	Artichoke, snap bean, green onion, Brussels sprouts, cut flowers
Extremely high	>60	Asparagus, broccoli, mushroom, pea, spinach, sweet corn

[1)]Vital heat (Btu/ton/24 hrs) = mg CO_2/kg/hr × 220.

the deterioration of leafy vegetables, immature fruit vegetables and root vegetables.

Decrease of chlorophyll content and brown color formation are sometimes observed in green vegetables. Carbohydrates and ascorbic acid (vitamin C) are chemical components that can be easily destroyed during the storage of vegetables. Protein degradation is a cause of the increase in the free amino acid content after harvest. Off-flavor takes place due to changes in the quality and quantity of volatile components.

Factors influencing vegetable quality after harvest

The quality of fresh vegetables starts deteriorating immediately after harvest. The quality changes affect the appearance, texture, flavor and nutritive value. The deterioration results from biological, biochemical and physical reactions taking place in the fresh products.

1 Handling procedures

Gentle and careful handling is essential at all stages from harvest to consumption : harvesting, trimming, washing, packaging, pre-cooling and transport. Rough handling causes mechanical injuries such as bruises, cuts, punctures, crushing and cracking.

Main significance of using plastic films for packaging is to avoid the mechanical injuries during the distribution of the products. Advanced handling methods for post-harvest treatments have been established in developed countries, but there are some difficulties to adopt the technology for financial reasons in some places, especially in developing countries.

2 Temperature

Temperature is the most important environmental factor affecting the quality of fresh horticultural products after harvest. Fig. 5 shows the effect of temperature on respiration rates and ethylene production in some vegetables. The results indicate that respiration rates and ethylene production of all vegetables increased rapidly with the increase of the temperature. Respiration rate of spinach showed the highest increase whereas that of onion and white radish was lower. Ethylene production of some vegetables increased with the increase of the temperature until 20 or 30°C, while in other vegetables it decreased at 30 or 40°C. This phenomenon is associated with the inactivation of the ethylene-forming enzyme (ACC oxidase) by heat. Due to the protein nature of an enzyme, thermal denaturation of the enzyme protein with increasing temperatures decreases the reaction rate. Up to about 45°C the reaction rate increases, but above 45°C it decreases due to protein denaturation. The temperature-enzyme reaction relationship is shown in Fig. 6.

A large number of investigations have been carried out on the relation of temperature to the quality maintenance of fresh produce. Experimental results were as follows.

Cabbage heads were stored at the temperatures of 0, 10, 20 and 30°C in separate perforated polyethylene bags and the quality was evaluated based on freshness rating scales. Changes in the quality during the 49 day period of the experiment are presented in Fig. 7. The results indicate that the quality of cabbage remained good at 0°C, and that the freshness deteriorated rapidly with the increase of the temperature. A freshness rating of 3 could be obtained for storage periods of 36, 18, 14 and 8 days at 0, 10, 20 and 30°C, respectively. These results show the importance of temperature as a post-harvest environmental factor for maintaining the quality of fresh produce.

Optimum temperatures for the storage of vegetables have been investigated widely and systematically by the researchers of the United States Department of Agriculture. They published a handbook indicating the recommended temperature and relative humidity, approximate storage life, highest freezing point, water content and specific heat for vegetables, fruits, nuts, cut flowers, florist greens, bulbs, cutting and nursery

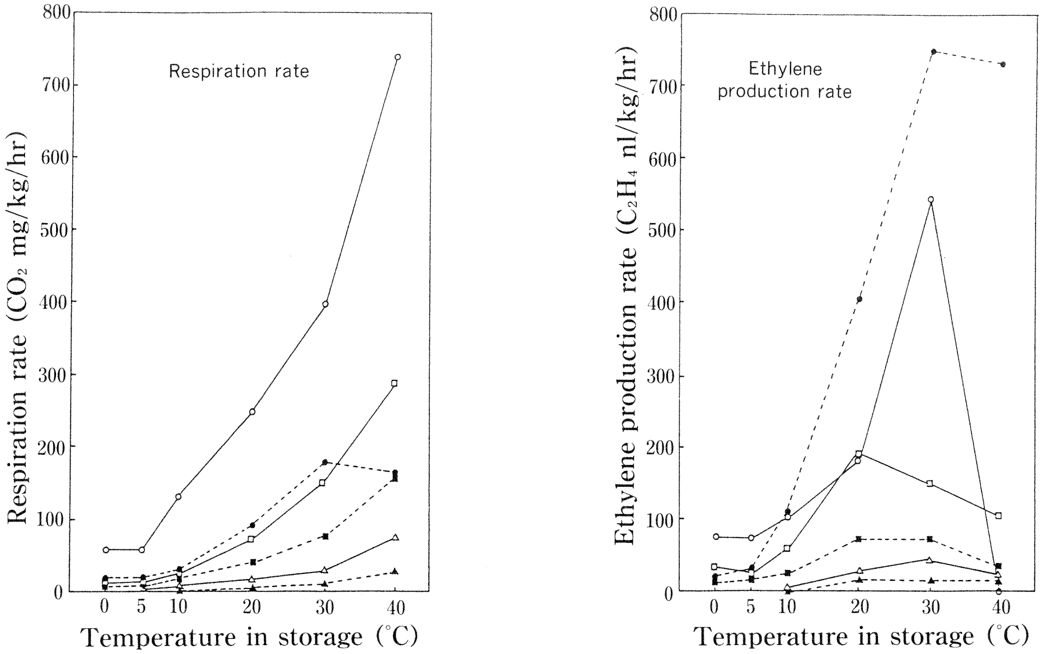


Fig. 5 Effect of temperature on respiration rate and ethylene production rate of various vegetables

○—○ : Spinach 'Atlas' ■—■ : Cabbage 'Hogyoku'
●—● : Eggplant 'Senryo 2 go' △—△ : White radish 'Miura'
□—□ : Strawberry bought at a supermarket ▲—▲ : Onion bought at a supermarket

Respiration rate and ethylene production rate were measured 24 hr to 48 hr after harvest and in case of spinach at 40°C 24 hr to 29 hr after harvest.

stocks (Hardenburg *et al.*, 1986). Table 6 shows the figures for vegetables. For most of the fresh vegetables the quality is best kept at temperatures around 0°C, which are slightly above the freezing points. However vegetables of the Cucurbitaceae family, e. g. cucumbers and melons, Solanaceae family, e. g. eggplants and tomatoes, and crops of tropical origin, e. g. bananas and pineapple, generally experience chilling injury when exposed to temperatures below 8 to 13°C.

3 Relative humidity

The relative humidity in the post-harvest environment not only affects the water loss, which leads to wilting or shrivelling, but also affects the activity of decay-causing organisms. Water loss which is brought about by stomatal transpiration is severe in commodities stored for a long time, especially in leafy vegetables and immature fruit vegetables.

Very high relative humidities are generally favorable for the growth of organisms, and the effect of high humidity is closely associated with that of temperature ; for many commodities relative humidity near saturation is suitable if the temperature is near 0°C.

Recommended relative humidity for most of the vegetables ranges from 90 to 100% ,

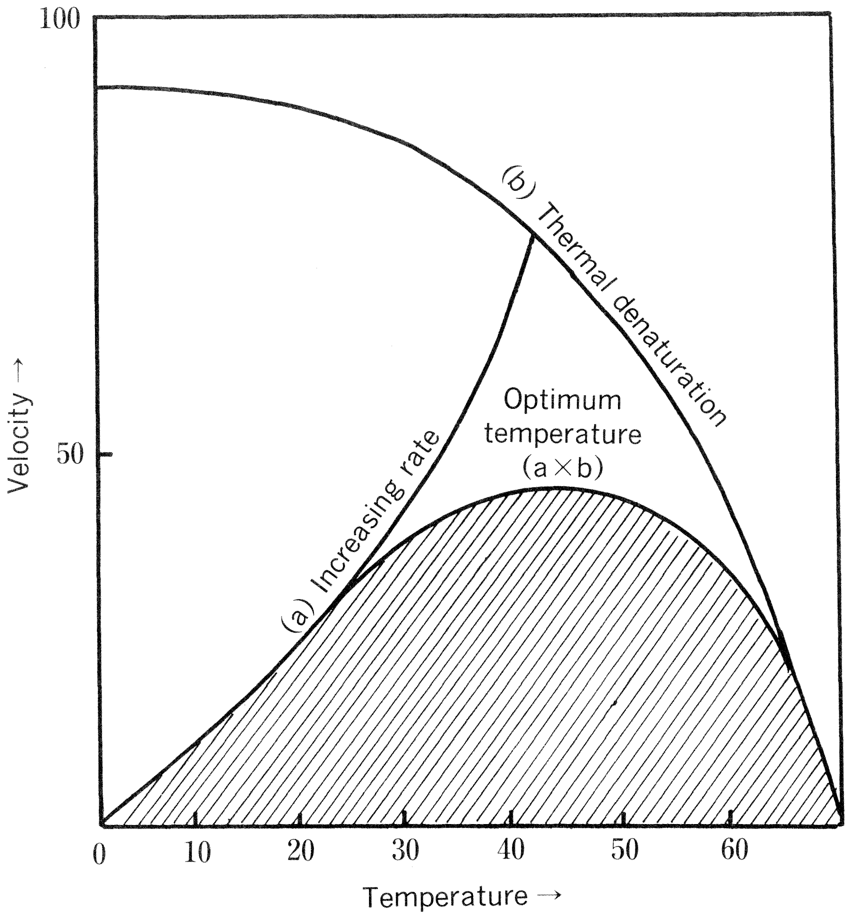


Fig. 6 Effect of temperature on reaction rate of an enzyme-catalyzed reaction

(a) represents the increasing rate of a reaction as a function of temperature.

(b) represents the decreasing rate as a function of thermal denaturation of the enzyme.

The shaded area represents the combination of (a×b).

that for fruits from 85 to 95% under optimum conditions of temperature around 0°C. Exceptions include garlic and ginger (65-70%), pumpkin and winter squash (50-70%). Packaging with plastic films, even if they are very thin wrap films, easily generates a high relative humidity within the package.

4 Atmosphere

Atmospheric conditions characterized by lower oxygen and higher carbon dioxide concentrations than those in air (20.95% oxygen, 0.03% carbon dioxide and 78.08% nitrogen)are effective in prolonging the storage life of fresh products. The controlled atmosphere (CA) storage, with lower oxygen and higher carbon dioxide concentrations, generally reduces plant respiration, enables to maintain the chlorophyll content, to decrease browning of injured tissues and slow down all the biochemical reactions.

An experiment with cabbage indicated that CA (3% oxygen, 5% carbon dioxide and

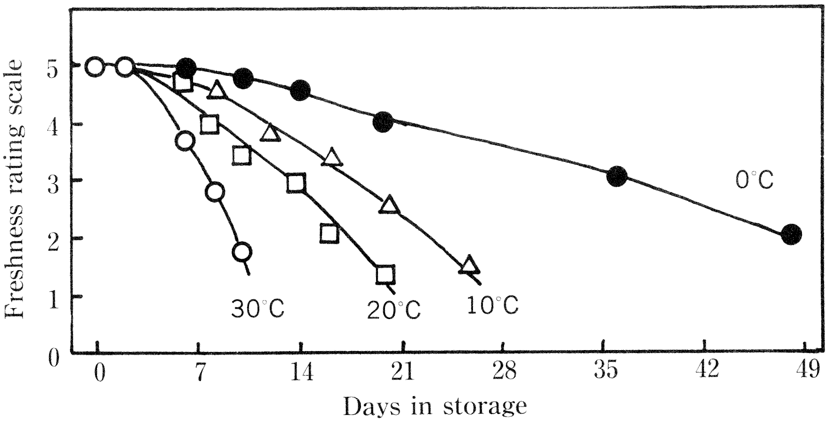


Fig. 7 Quality deterioration of cabbage stored at various temperatures

Cabbage, cv. 'Derishasu', was harvested on June 9, 1987 from the field of NIVOT. Selected 5 samples were subsequently packaged in a perforated polyethylene bag (low density, 100μm thickness) to prevent wilting.

Each package was stored at the temperatures of 0°, 10°, 20° and 30°C for the indicated period. Stored cabbage quality was evaluated every day by 3 panelists using the freshness rating scale shown in Table 2.

92% nitrogen) storage was more effective than air storage at 1°C for 19 weeks (Lougheed, 1983) : CA storage had a beneficial effect on all measured criteria of quality : visual quality, chlorophyll content, fresh weight loss and trim loss.

Recent study on maintenance technology for freshness of vegetables

CA storage, modified atmosphere (MA) storage are promising methods for the storage of vegetables. MA storage is a term used to keep the produce under an atmosphere modified by package, over wrap, box liner or pallet cover.

Effect of CA conditions on the quality of broccoli during storage is illustrated in Fig. 8.

Table 6 Recommended temperature and relative humidity, approximate storage life, highest freezing point, water content, and specific heat for fresh vegetables in commercial storage[1)]

Commodity	Temperature (°C)	Relative humidity (%)	Approximate storage life	Highest freezing Point (°C)	Water content (%)	Specific heat (Btu/lb°F)
Asparagus	0-2	95-100	2-3 weeks	−0.6	93.0	0.94
Beans, green or snap	4-7	95	7-10 days	−0.7	88.9	0.91
Broccoli	0	95-100	10-14 days	−0.6	89.9	0.92
Cabbage, early	0	98-100	3-6 weeks	−0.9	92.4	0.94
Cabbage, late	0	98-100	5-6 months	−0.9	92.4	0.94
Cabbage, Chinese	0	95-100	2-3 months	—	95.0	0.96
Carrot, mature	0	98-100	7-9 months	−1.4	88.2	0.91
Cauliflower	0	95-98	3-4 weeks	−0.8	91.7	0.93
Celery	0	98-100	2-3 months	−0.5	93.7	0.95
Corn, sweet	0	95-98	5-8 days	−0.6	73.9	0.79
Cucumber	10-13	95	10-14 days	−0.5	96.1	0.97
Eggplant	8-12	90-95	1 week	−0.8	92.7	0.94
Carlic	0	65-70	6-7 months	−0.8	61.3	0.69
Ginger	13	65	6 months	—	87.0	0.90
Horseradish	−1.0-0	98-100	10-12 months	−1.8	94.6	0.80
Leeks	0	95-100	2-3 months	−0.7	85.4	0.88
Lettuce	0	98-100	2-3 weeks	−0.2	94.8	0.96
Melons						
Cantaloupe (full-slip)	0-2	95	5-14 days	−1.2	92.0	0.94
Honey dew	7	90-95	3 weeks	−0.9	92.6	0.94
Watermelon	10-15	90	2-3 weeks	−0.4	92.6	0.94
Mushroom	0	95	3-4 days	−0.9	91.1	0.93
Okra	7-10	90-95	7-10 days	−1.8	89.8	0.92
Onion, dry	0	65-70	1-8 months	−0.8	87.5	0.90
Parsley	0	95-100	2-2.5 months	−1.1	85.1	0.88
Pea, green	0	95-98	1-2 weeks	−0.6	74.3	0.79
Pepper, sweet	7-13	90-95	2-3 weeks	−0.7	92.4	0.94
Pumpkin	10-13	50-70	2-3 months	−0.8	90.5	0.92
Radish, spring	0	95-100	3-4 weeks	−0.7	94.5	0.96
Radish, winter	0	95-100	2-4 months	—	—	—
Squash, summer	5-10	95	1-2 weeks	−0.5	94.0	0.95
Squash, winter	10	50-70		−0.8	85.1	0.88
Tomato, mature-green	13-21	90-95	1-3 weeks	−0.6	93.0	0.94
Tomato, firm-ripe	8-10	90-95	4-7 days	−0.5	94.1	0.95
Turnip	0	95	4-5 months	−1.0	91.5	0.93

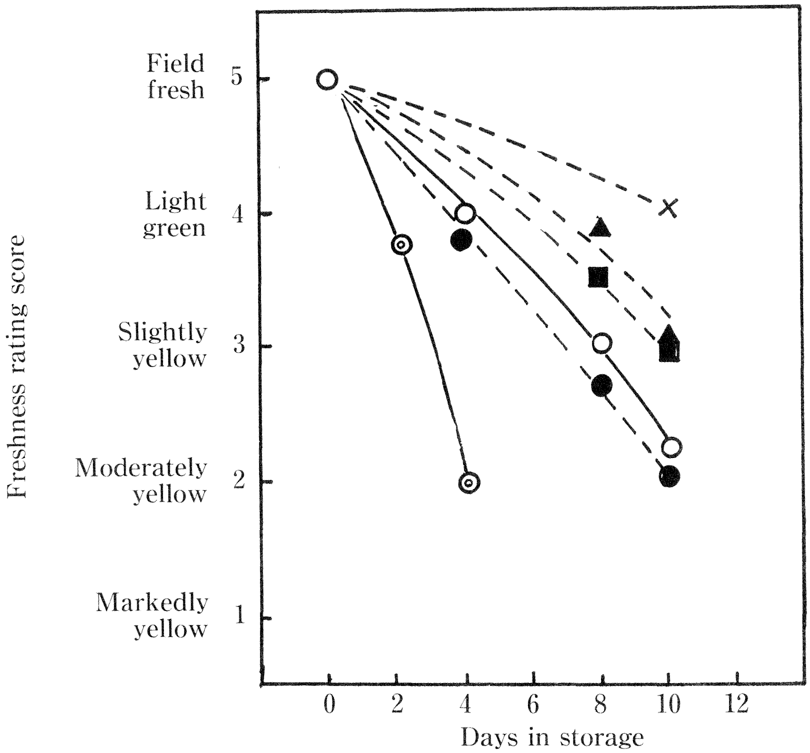


Fig. 8 Changes in the quality of broccoli during CA storage

Medium size broccoli was purchased from an agricultural cooperative association on Oct. 28, 1988, and then 5 broccoli heads in each experiment were stored in a 10 l chamber under various controlled atmosphere conditions (the mixed atmosphere was passed through a chamber at the speed of 100 ml/min).

○—○ : Air, 10°C
◎—◎ : Air, 15°C
●···● : 5% O_2+5% CO_2+90% N_2, 15°C
■···■ : 5% O_2+10% CO_2+85% N_2, 15°C
▲···▲ : 2% O_2+5% CO_2+93% N_2, 15°C
×···× : 2% O_2+10% CO_2+88% N_2, 15°C

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Discussion

Henry, G. (CIAT) : Did you make a classification of the optimum time of storage for various vegetables for certain temperatures?

Answer : Yes we did. We decided to make our own classification after we realized that the optimum conditions of vegetable storage outlined in the handbook published by the U. S. Department of Agriculture may not be fully suitable for the vegetables cultivated in Japan. Up to now the following vegetables have been covered : cabbage, broccoli, lettuce, spinach, tomatoes, cucumbers as well as a few tropical crops.