JARQ 35(2), 105 – 115 (2001) http://www.jircas.affrc.go.jp

Quality Preservation of Fruits and Vegetables by Simple Spotted Cooling System and/or by Packaging Using New Plastic Films

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Abstract

A simple spotted cooling unit (SCU) and micro-perforated plastic films with a high gas permeability were developed in order to improve the distribution system of fruits and vegetables practically. SCU with a bellows structure was designed to maintain the air temperature at about 15ºC. When spinach which had been pre-cooled and transported at near 15ºC to a collection and delivery center in summer, was stored within SCU, less than 10% of the L-ascorbic acid content decreased for about 10 h. On the other hand, nearly 50% of the L-ascorbic acid content decreased when spinach was left in open-air without any remarkable changes in appearance. Micro-perforated (MP) films were produced by processing the surface of the films by passing through press-perforating rollers with a good reproducibility. The use of MP films, which were laminated with oriented polypropylene and polyethylene and showed a gas permeability of O_2 19,000 and CO_2 28,000 mL/(m^2 • 24 h • 101.325 kPa) at 15ºC, respectively, and thickness of about 40 µm, enabled to obtain practical and effective hermetic packaging for the preservation of broccoli for 14 days at 15ºC without appreciable changes in appearance. Utilization of SCU and MP film packaging or the combination of the two was found to be suitable for freshness preservation in the distribution of fruits and vegetables.

Discipline: Postharvest technology / Food
Additional key words: cold chain, modified atmosphere packaging, micro-perforated film with high gas permeability

Introduction

With the progress and diversification of dietary life, the demand for fresh foods with high quality has been increasing. Although the quality of fresh foods or fruits and vegetables (produce) is primarily dependent upon the varieties and cultivation technology, postharvest technology has become increasingly important recently[14)].

Quality components are generally specified as properties of the produce, and can be largely classified into 3 groups, i.e. fundamental properties, functional properties, and secondary properties (Fig. 1)[5)]. Each property depends on many types of chemical and physical charac-

This paper is based primarily on the reports[2,3)] of our previous studies on the development of a new system for production, distribution and processing of agricultural commodities carried out by the Project Research Team No.4, National Agriculture Research Center in collaboration with Asahi Kogyosha for the spotted cooling unit (from October 1993 to March 1995), and with Toppan Printing Co., Ltd. for new plastic films (from June 1993 to March 1996).
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Received 1 December 1999, accepted 21 November 2000.

- Quality components
  - Fundamental properties
    - Nutritional properties
      - Proteins, fats (oils), carbohydrates, fiber, pectin, other high molecular components
      - Amino acids, saccharides, organic acids, fatty acids, water, other low molecular components
      - Vitamins, minerals, other trace elements
    - Safety
      - Residual agricultural drugs or agrochemicals, natural toxins, heavy metals, harmful microorganisms, microbial toxins, others
  - Functional properties
    - Preference properties
      - Color — Carotenoids, flavonoids, chlorophylls, anthocyanins, other pigments, optical properties, color properties, brightness, tint, gloss, darkness
      - Shape — Apparent shape, size, uniformity, damage, insect damage, injury
      - Smell — Smell components, alcohols, esters, aldehydes, terpenes, aroma
      - Taste — Sweetness, saltiness, hot taste, acid taste, bitter taste, deliciousness, astringency, taste components, sugars, organic acids, amino acids, fatty acids, nucleic acids, salts
      - Dynamic properties — Softness, firmness, brittleness, crushing resistance, penetration resistance, shearing resistance, viscous elasticity, tooth touch, tongue touch, smoothness, passage through throat, electric conductivity, cell structure, texture affecting components (protein, starch, fiber, etc.)
    - Physiological control functions — Antimutagenicity, antitumor activity, antioxidation activity, blood pressure control function, immunity activation, eyesight recovery, physiologically active components (functional peptides, lipids, etc.)

<< Secondary properties >>

- Distribution properties — Stability in preference properties (transpiration/ water, components, appearance, texture, respiration, cold injury), handling properties (harvesting, packaging, transport, etc.)
- Processing properties — Suitability for processing (product color, taste, texture, etc., materials' yield, price, etc.)
- Properties added — Convenience, pleasure, culture, rationality, personal values, economy

Fig. 1. Quality components of fruits and vegetables (modification of Ishitani, 1993[5])

Table 1. Standards for purchase-decision and freshness-determination by consumers (modification of Ishitani, 1993[5])

(%)

Standard for purchase-decision	Persons who gave a positive reply*		Standard for freshness-determination	Persons who gave a positive reply*	
	Vegetables	Fruits		Vegetables	Fruits
Freshness	86	59	Fresh-looking	53	21
Apparent color and gloss	11	18	Color and gloss	48	62
Grade (size and weight)	6	9	Shape	19	27
Taste (maturity, sweetness, acidity)	20	42	Hardness/softness	20	17
Production area and brand name	10	18	Weight	13	27
Produce in season	50	42	Any produce and any season	5	4
Price, others	17	12			

* The persons who answered questions were allowed to give several answers.

teristic components or factors. Table 1 shows the answers obtained from a questionnaire on the standard for purchase-decision when consumers buy produce in Japan[5]. The results indicate that the consumers pay a great deal of attention to freshness when they buy produce. Therefore, preservation of freshness or quality is very important in the processing after harvest.

We developed a simple spotted cooling unit[2] and new plastic films having a high gas permeability with micro-perforation[3], to establish a practical and effective system for the preservation of freshness and quality of produce.

Table 2. Principle, purpose, technologies, and materials or equipment for freshness preservation of fruits and vegetables (modification of Ishitani, 1993[5])

Principle	Purpose	Technologies	Materials / Equipment
Preservation at low temperature Distribution at low temperature	Restriction of respiration Restriction of transpiration	Pre-cooling Low temperature preservation	Pre-cooling facilities, pre-cooling room, heat insulation box, container, refrigerator truck, cooling agents, temperature monitoring label
Control of moisture	Prevention of weight loss and withering Prevention of dewing and spoilage	Packaging Coating	Packaging materials (plastic films), moisture controller, anti-haze agent, water vapor permeability of packaging materials, anti-microbial packaging materials, immersion and spraying of safe chemicals
Control of ambient gas	Restriction of respiration and metabolism Restriction of browning and offensive odor	Modified atmosphere packaging Controlled atmosphere storage Low atmosphere pressure	Type, thickness, pinholes of packaging materials, control of concentrations of O_2 and CO_2, control of the environmental temperature and humidity, reduced-pressure container
Removal of ethylene	Restriction of senescence or aging and metabolism	Removal by adsorption and decomposition	Ethylene adsorbent, ethylene decomposer
Control of ethylene synthesis	Restriction of senescence or aging and metabolism	Physiologically active substances	Packaging materials coated or formed with freshness preservatives

Basic technology for freshness preservation and current situation

As produce is alive even after harvest, deterioration changes in the components or the factors are usually inevitable in subsequent processing, and the changes are generally rapid and substantial in vegetables. In general, respiration and transpiration of produce are accelerated as the ambient temperature increases, which results in a remarkable deterioration of freshness and loss of useful components or of quality. Therefore, restriction of respiration and transpiration is very effective and important for the preservation. Table 2 shows the principles and technologies for the preservation of freshness of produce[5]. Cooling of produce, especially in summer, and packaging are useful and practical technologies[6,7,16,18,22,23]. Data from the International Institute of Refrigeration recommend that produce be distributed at a low temperature (above 0ºC and below 10ºC)[9].

Pre-cooling technology has been well developed[19], and about 3,400 pre-cooling units, based on air-forced cooling system, differential pressure cooling system and vacuum cooling system, had been developed by 1996 for producing centers under ZEN-NOH (National Federation of Agricultural Cooperative Associations) in Japan[8]. The pre-cooled produce is transported by refrigerator trucks or keeping-cool trucks to wholesale markets or collection and delivery centers near large consumer cities. The distribution conditions have been considerably improved recently.

Development of a simple spotted cooling unit (SCU)

The framework or basic part of the cold chain system has been almost fully developed in the distribution process of produce in Japan[15]. However, the produce, in most cases, is practically distributed at 10 to 20ºC [5]. Investigations on the actual conditions of temperature control in the distribution process, revealed that temperature of cold produce rose by 5 ~ 10ºC [4,13,20] when the produce reached the wholesale markets or the collection and delivery centers, depending on the ambient temperature in summer days during the period preceding auction and re-delivery. The produce which became warm was usually transported without any subsequent cooling to supermarkets, retail stores or terminal centers[4]. The rise in the temperature of the produce in the wholesale markets or the collection and delivery centers is due to the fact that most of the wholesale markets and collection and delivery centers are insufficiently or not equipped with refrigerated systems. Thus, a discontinuation in the cold chain system occurs in the sequence between the wholesale markets or the collection and delivery centers and consuming areas.

As described above, most of the collection and delivery centers or wholesale markets lack cooling equipment in the yards, because of the cost and hindrance to transfer and subdivision work using forklift trucks. In order to obtain a convenient and low-cost cooling distribution system of produce, we developed a simple spotted cooling unit (SCU, Fig. 2)[2], 5 m in width, 3.5 m in depth, and 3.2 m in height, and set it up at a subdivision platform of the Yamato collection and delivery center of ZEN-NOH, Yamato, Kanagawa, Japan. SCU was designed to maintain the air temperature at about 15ºC (Table 3)[2]. Cool air is generated with 2 indoor units of air conditioner (16.74 kj/unit) which are fixed on the ceiling of SCU (Fig. 2 bottom). The lowest part which has a heavy iron frame can be lifted up to a height of 3 m where the fork of the forklift truck is not caught in (Fig. 2 top and middle). The bellows are made of cheap polyester sheets. All the equipment or parts consist of cheap materials available in the market. Cooling temperature of 15ºC with SCU was selected because pre-cooled produce was transported around 15ºC in many cases[4], and con-

Table 3. Efficiency of simple spotted cooling (SCU) applied in summer (modification of Horita et al., 1997[2]) [a]

Measuring points	Temperature (ºC)	Temperature[b] (ºC)	Relative humidity (%)	Relative humidity[b] (%)
Open-air	18.8 ~ 29.5	29.5	59 ~ 99	68
Center of SCU	14.5 ~ 16.3	16.3	75 ~ 90	75
Lower position in SCU	14.5 ~ 15.8	15.8	75 ~ 89	75
Blow-off site of cooler	13.0 ~ 15.0	14.0	85 ~ 99	85
Intake site of cooler	14.5 ~ 15.8	15.8	77 ~ 86	77

a): Performance test was conducted at the subdivision platform of the Yamato collection and delivery center of ZEN-NOH (National Federation of Agricultural Cooperative Associations), Yamato, Kanagawa, Japan.
b): Temperature or relative humidity when the highest temperature (29.5ºC) was recorded in open-air.

Fig. 2. Simple spotted cooling unit (SCU)[2)]

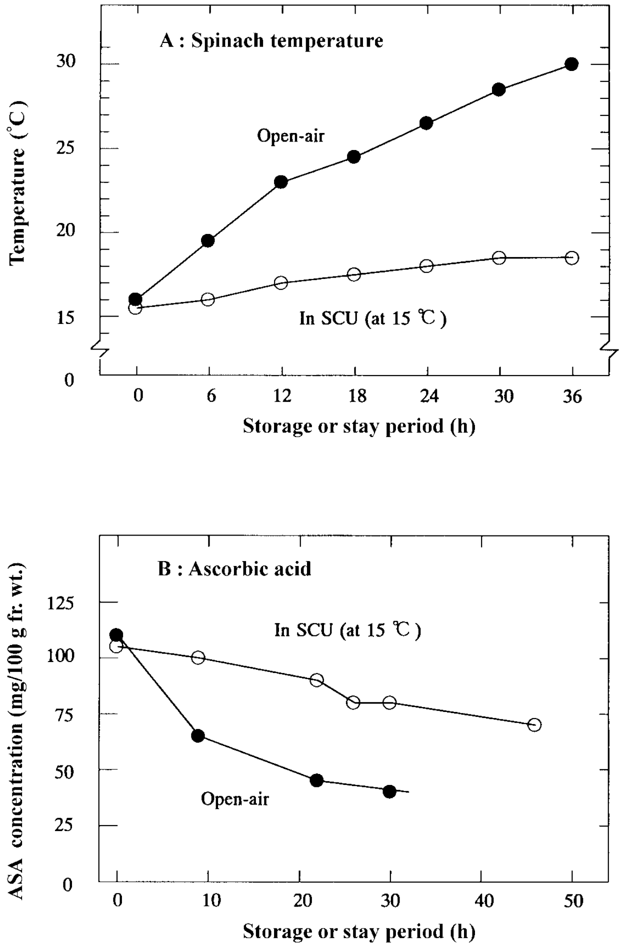

Fig. 3 Effect of cool temperature on keeping of freshness in spinach (modification of Horita et al., 1997[2])

densation was hardly observed at 15ºC on the surface of the produce when taken out in open-air even in summer. Another reason was that we attempted to utilize underground water at 13 to 14ºC with a wet-cooling type SCU[12].

When spinach in open top polyethylene bags which had been pre-cooled, packed in corrugated cardboard boxes and transported to the yard of the collection and delivery center by refrigerator trucks, was taken out in open-air (28ºC) and allowed to stand for 36 h, the temperature of spinach rose by 14ºC (Fig. 3-A)[2]. No changes in the appearance of spinach were visually observed for 9 h after the onset of the experiment. However, the content of L-ascorbic acid (ASA) decreased to nearly 50% during this period (Fig. 3-B). On the other hand, for spinach stored in SCU, the temperature rose by only 3ºC (Fig. 3-A), and no changes in the appearance were observed during a 30 h period in the collection and delivery center. The content of ASA decreased by only 5% at 9 h after storage (Fig. 3-B). A 9 h period of storage, in many cases, is common before redistribution for most of the types of produce. It was reported that a decrease in the ASA content in broccoli, which deteriorates fast, began immediately after harvest before any changes in the appearance could be visually detected[11,21,23], and the content of ASA is considered to be a good indicator of freshness[21]. The loss of fresh weight of spinach was minimal for 30 h (a decrease of only 0.7 and 0.5% in open-air and in SCU, respectively).

Although a temperature of 15ºC is not considered to be sufficiently low to decrease the metabolism of produce, effective reduction of the decrease in the ASA content, that is, in freshness with SCU in summer, indicates that it is very important to maintain the produce continuously at low temperatures.

Development of micro-perforated (MP) gas-permeable plastic films

As indicated above, transpiration and respiration can be well controlled by hermetic packaging of produce with plastic films[6, 7]. However, packaging often accelerates the deterioration of the produce by anaerobic respiration due to the shortage of oxygen in the package caused by the low gas permeability of the films[22,23]. Therefore, films with a high oxygen permeability are needed for produce with a high respiration rate, such as broccoli[6,7,17], spinach[6], asparagus[6], shiitake mushroom[6] and enokitake mushroom[6]. Some types of plastic films have been examined from the view point of freshness preservation of produce[6,7], and films with a high gas permeability have been developed on an experimental basis. Table 4 shows polyolefin films with a high gas permeability which have been developed recently[5]. Low-density polyethylene (LDPE) films (20, 25, or 30 µm in thickness) display a considerably higher oxygen permeability than others. Fig. 4 shows the degree of oxygen permeability and water vapor transmission of plastic films (25 to 30 µm in thickness) and the factors associated with changes in the quality of broccoli stored at 15ºC (● : position for favorable conditions)[5]. As for the oxygen permeability, broccoli requires a value around 10,000 mL/(m^2 • 24 h • 101.325 kPa). Although the LDPE films 20 µm in thickness shown in Table 4 appeared to be suitable in terms of gas permeability, they usually lacked the strength required in the distribution process. In this regard, new films with a high oxygen permeability and sufficient strength should be developed.

In order to develop plastic films with a high oxygen permeability and sufficient strength, we manufactured laminated films made of oriented polypropylene (OPP) which is a transparent and strong material, with polyeth-

Table 4. Gas permeability rate and ratio of representative polyolefin films (modification of Ishitani, 1993[5])*

Temperature, thickness	Permeability (mL/(m^2・24 h・101.325 kPa))												Remarks
	Low-density polyethylene			High-density polyethylene			Cast polypropylene			Oriented polypropylene			
	N_2	O_2	CO_2	N_2	O_2	CO_2	N_2	O_2	CO_2	N_2	O_2	CO_2	
20ºC, 20 µm	1,400	4,000	18,500	220	600	3,000	200	860	3,800	100	550	1,680	Minakuchi (1990),
	1	*2.9*	*13.2*	*1*	*2.7*	*13.6*	*1*	*4.3*	*19.0*	*1*	*5.5*	*16.8*	Industrial Material
		1	*4.6*		*1*	*5.0*		*1*	*4.4*		*1*	*3.1*	
21ºC, 20 µm	3,480	14,630	56,100	810	4,920	11,220							Ibonai (1990),
	1	*4.2*	*16.1*	*1*	*6.1*	*13.9*							Primer Handbook of Plastics
		1	*3.8*		*1*	*2.3*							
20ºC, 20 µm	3,100	12,000	42,000							730	3,000	9,100	Ikari (1990)
	1	*3.9*	*13.5*							*1*	*4.1*	*12.5*	
		1	*3.5*								*1*	*3.0*	
20ºC, 30 µm	1,900	6,600	24,900							300	1,300	4,500	National Federation of Agricultural
	1	*3.5*	*13.1*							*1*	*4.3*	*15.0*	Cooperative Associations, Japan (1990)
		1	*3.8*								*1*	*3.5*	
25ºC, 30 µm		5,800	27,700								1,600	5,900	Ishitani (1990)
		1	*4.6*								*1*	*3.7*	
Average ratio													
$N_2 : O_2 : CO_2$	*1*	*3.6*	*14.0*	*1*	*4.4*	*13.8*	*1*	*5.3*	*19.0*	*1*	*4.6*	*14.8*	
($O_2 : CO_2$)		*(1*	*4.1)*		*(1*	*3.7)*		*(1*	*4.4)*		*(1*	*3.3)*	

*: Data before 1990 in the original Table were omitted.

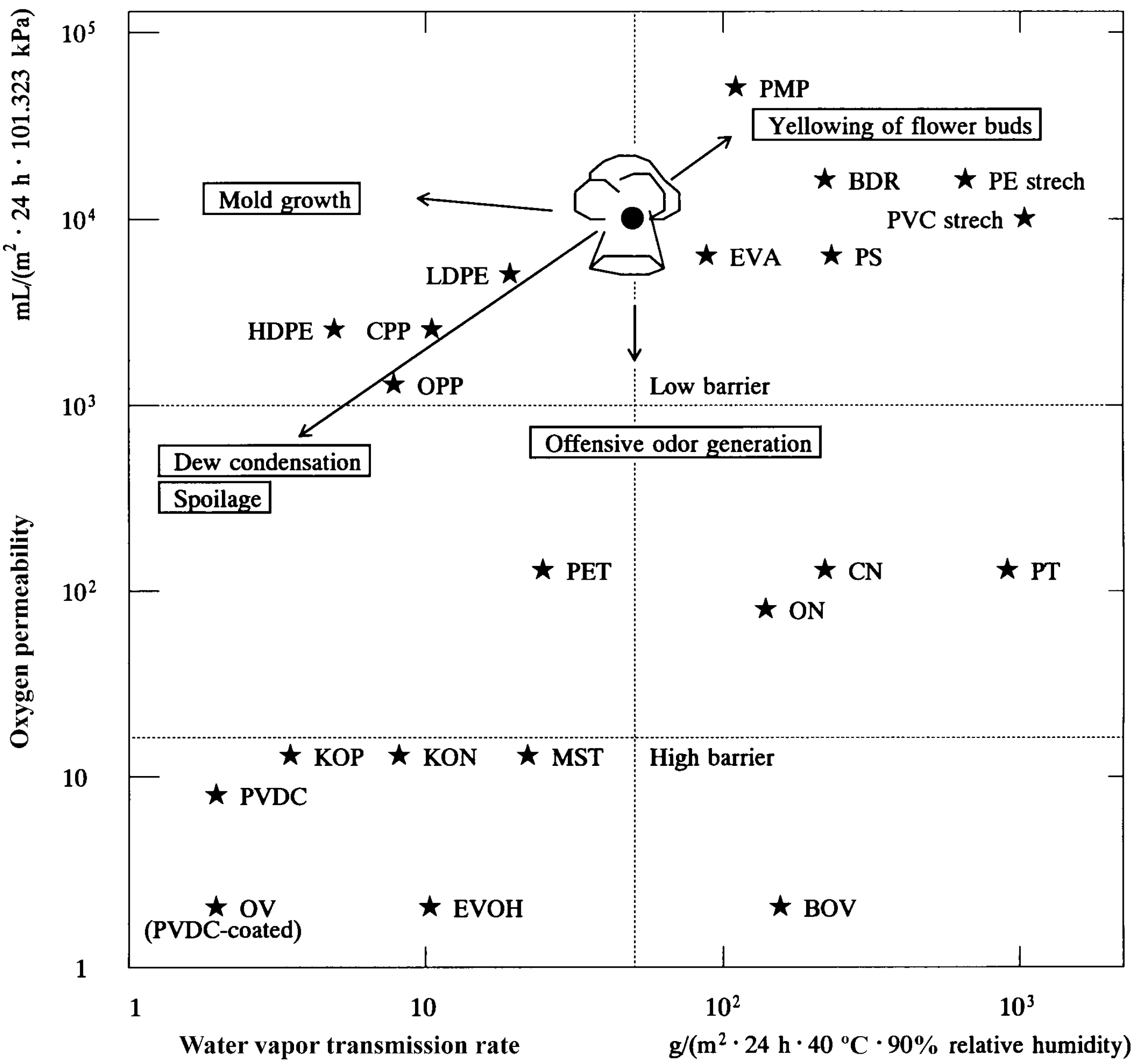

Fig. 4. Oxygen permeability and water vapor transmission rates of plastic films (25–30 µm in thickness) and factors for changes in quality of broccoli during storage at 15°C (modification of Ishitani, 1993[5])

● : Position for favorable conditions for broccoli.

LDPE: Low density polyethylene,	PET: Polyethylene terephthalate (polyester),
HDPE: High density polyethylene,	PVC: Polyvinyl chloride,
OPP: Oriented polypropylene,	PVDC: Polyvinylidene chloride,
CPP: Cast polypropylenethylene,	KOP: PVDC-coated OPP,
ON: Oriented nylon (polyamide),	KON: PVDC-coated ON,
CN: Cast nylon,	EVOH: Ethylene vinyl alcohol copolymer,
BDR: Polybutadiene,	EVA: Ethylene vinyl acetate copolymer,
PMP: Polymethylpentene,	PS: Polystyrene,
BOV: Biaxially oriented vinylon,	PT: Plain cellophane,
OV: PVDC-coated oriented vinylon,	MST: Polymer-type moisture-proof cellophane.

ylene (PE). Then the films (MP-OPP/PE) could be processed stably and with a high level of reproducibility by a special micro-perforation technique[10]. Fig. 5 shows a vertical section of MP-OPP/PE[3]. Observation of the films with a scanning electron microscope revealed micro-perforations of around 50 to 100 µm in diameter, which contribute to a very high oxygen permeability ranging from 10^3 to 10^5 mL/(m^2•24 h•101.325 kPa). We manufactured and examined also other new films made of polymethylpentene (PMP) with a tenfold higher oxygen permeability than the PE with the same thickness, but which displayed a lower mechanical strength. Figs. 6 and 7 show the permeability properties of MP-OPP/PE films and PE or PMP films to oxygen and carbon dioxide,

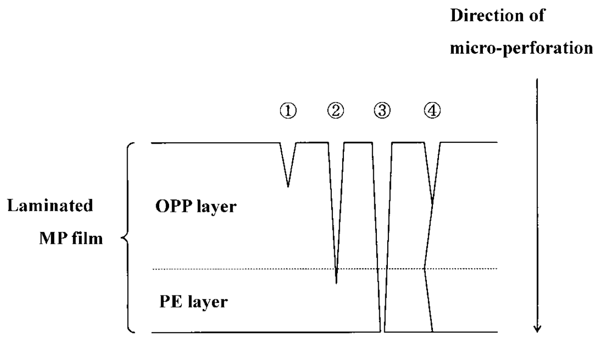

Fig. 5. Vertical section of micro-perforated (MP) laminated film (modification of Horita et al., 1998[3])
Micro-perforation can be made also from PE side.
①: slight hollow, ②: deep hollow, ③: full perforation, ④: hollow and crack.
OPP and PE: Abbreviations are the same as in Fig. 4.

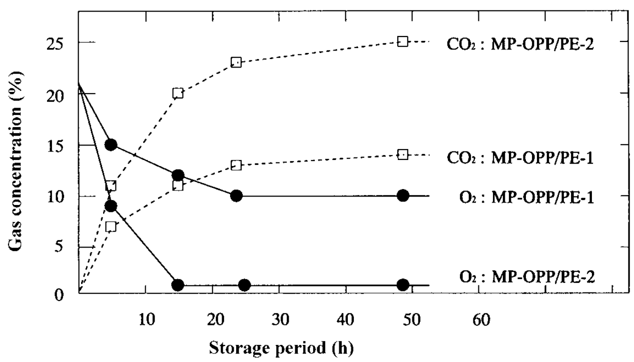

Fig. 6. Changes in oxygen and carbon dioxide concentrations in hermetic packaging with micro-perforated films (MP-OPP/PE) during storage of broccoli at 20°C (modification of Horita et al., 1998[3])
MP-OPP/PE-1 and MP-OPP/PE-2: Refer to Table 5.

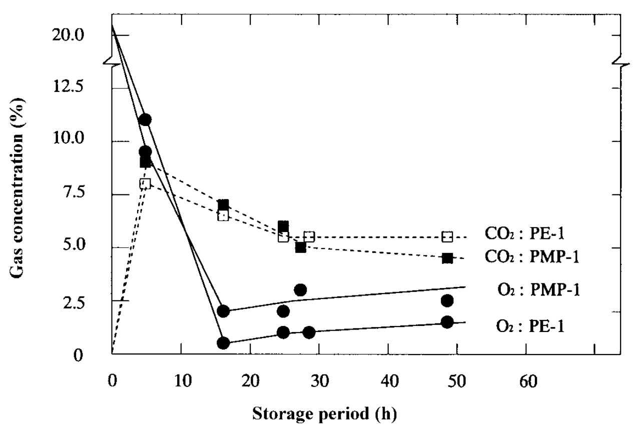

Fig. 7. Changes in oxygen and carbon dioxide concentrations in hermetic packaging with MPM or PE films during storage of broccoli at 20°C (modification of Horita et al., 1998[3])
PMP-1 and PE-1: Refer to Table 5.

respectively, when broccoli was hermetically packaged and stored at 20°C[3]. Concentrations of oxygen and carbon dioxide in the MP-OPP/PE-1 and MP-OPP/PE-2 bags were equilibrated at around 10, 13, 1 and 25%, respectively (Fig. 6). The permeability ratio of carbon dioxide to oxygen for the MP-OPP/PE films was calculated to be 1.5 from the data in Table 5[3], which indicates that the MP-OPP/PE films show a limited selective permeability to carbon dioxide. Thus the concentration of carbon dioxide in the MP-OPP/PE-2 bag was equilibrated at high levels. Films of this type can be used for produce in which respiration is controlled by carbon dioxide. On the other hand, PE and PMP films show a higher selective permeability to carbon dioxide. The permeability ratio of carbon dioxide to oxygen for the PE and PMP films was calculated to be about 5 and 4, respectively, from the data in Table 5. Thus, the concentrations of oxygen and carbon dioxide in the PMP-1 bag and in the PE-1 bag were equilibrated at around 3, 5, 2 and 6%, respectively (Fig. 7). Films of this type are preferable for produce prone to carbon dioxide injury. Efficiency of these films in packaging for freshness preservation of broccoli is indicated in Table 5. The MP-OPP/PE-2, PMP-2 and PE-1 films showed good results in terms of preservation of freshness of broccoli stored at 15°C. However, since these PMP and PE films lack mechanical strength, they can not be practically used in the distribution process of produce. Any type of packaging reduced the decrease in the ASA content in broccoli[3]. MP-OPP/PE films were found to be preferable for freshness preservation of banana[18], green Japanese apricot[1], and enokitake mushroom[3], as well as broccoli. Since Japanese apricot is consumed at the immature green stage for making pickles in Japan, aging must be controlled as much as possible. When the new gas-permeable MP-OPP/PE film with 28,000 mL/(m^2 • 24 h • 101.325 kPa) was used for packaging, the green color of Japanese apricot was well preserved for 8 days and further maintained in the presence of an ethylene-removing agent. Color of Japanese apricot in open-air turned yellow. In the case of banana, browning of peel with pitting which occurs in open-air storage could be effectively alleviated by hermetic packaging using MP films with adequate oxygen permeability without deterioration of the inner flesh. As for enokitake mushroom, freshness and sweetness were well preserved, and the mushrooms were edible without cooking after purchase from a supermarket.

As the MP-OPP/PE films which display a range of gas permeability can be constantly produced now, some of these films can be used for a wide variety of produce with various types of respiration levels.

Table 5. Effects of gas-permeable films on freshness preservation of broccoli (modification of Horita et al., 1998[3])

Films[a] (thickness µm)	Permeability[b] mL at 15ºC		Storage temperature	Stable period	Final concentration[c] (%)		Final condition of broccoli[d]
	O_2	CO_2	(ºC)	(day)	O_2	CO_2	
No	–	–	15	3	–	–	Y
No	–	–	20	2	–	–	Y
PE-1 (15.1)	7,000	36,000	15	7	5.0	4.5	PR
PE-2 (18.4)	5,400	29,000	20	3	1.5	5.5	D, OF, R
MP-OPP/PE-1 (39.3)	67,000	100,000	15	4	12.0	10.5	Y, OF
			20	4	9.5	13.0	Y, OF, R
MP-OPP/PE-2 (39.7)	19,000	28,000	15	14	5.0	16.5	PR
			20	2	1.0	25.0	D, OF
MP-OPP/PE-3 (39.6)	9,000	10,000	15	2	1.0	25.0	OF
			20	2	1.0	25.0	D, OF
PMP-1 (29.9)	36,000	140,000	15	3	11.0	3.0	Y, OF
			20	2	6.0	4.5	Y, OF
PMP-2 (33.6)[e]	20,000	79,000	15	9	3.0	4.5	Y
			20	4	3.0	5.0	Y, OF

a): PE, polyethylene; MP, micro-perforated; OPP, oriented polypropylene; PMP, polymethylpentene; OPP/PE, laminated film.
b): mL/(m^2 • 24 h • 101.325 kPa).
c): Equilibrated inner gas concentration in packaging at the end of storage.
d): Deterioration of the flower buds appearing at the end of storage. Y, yellowing; D, partly decomposed; OF, off flavor generation; R, rotted; PR, partly rotted.
e): PMP laminated with PE.

Conclusion

In this paper it was showed that low temperature and modified atmosphere hermetic packaging are very useful techniques for the preservation of freshness in the distribution process of produce. These techniques are based on the control of the physiological activity or enzyme reactions of individual produce. Therefore, analysis of the physiological properties, especially in the distribution process, is very important. Prediction technology of the amount of respiration (and amount of ethylene generation) of produce in the process of distribution should be developed. Analysis of preferential permeability of gases such as oxygen, carbon dioxide and ethylene should be promoted, too. If appropriate gas permeability could be obtained for producers and distributors, transportation area and shelf life could be adequately determined, which may contribute to the supply of high quality produce to consumers. Furthermore, detailed investigations on the optimum range of distribution temperatures for individual produce may enable to determine the temperature required precisely according to seasons and distribution channels. Eventually, it will become possible to distribute produce with a high degree of freshness.

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