減圧貯蔵法における減圧解除後の果実呼吸量及びエチレン生成の特長

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Characteristics of Respiration and Ethylene Production in Fruits Transferred from Low Pressure Storage to Ambient Atmosphere[1]

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Summary

Oxygen is an essential factor for the synthesis of ethylene in harvested fruit, and an almost immediate cessation of ethylene production by fruit occurs under anaerobic conditions such as 100% nitrogen. Fruits which have been prevented from producing ethylene anaerobically are able to produce ethylene when transferred to air at a rate higher than that by control fruit in air and without a lag period.

In this paper, we studied whether or not fruits transferred from an environment at a low pressure or low partial pressure of oxygen to an environment at a normal pressure show ethylene production in the same manner as mentioned above. In Japanese pear and tomato fruits which are classified as climacteric in respiration during ripening, pear fruits were stored at a pressure of 190 and 285 Torr for 36 days then transferred to the ambient atmosphere after 8, 15, 22 or 36 days while tomato fruits were stored for 40 days at the same pressures then transferred to the ambient atmosphere after 40 days. The ethylene production rates of the fruits transferred from low pressure storage were measured by determining ethylene accumulation from 0 to 3 hours, 3 to 6 hours, 6 to 12 hours and 12 to 24 hours after transfer. These fruits showed higher rates than fruits which had been stored at normal pressure. However, the respiration rates of fruits transferred from low pressure storage to an ambient atmosphere were lower than those of fruits stored at normal pressure. In orange fruits whose respiration is non-climacteric, the ethylene production and respiration rates of fruits after transfer were lower than that of fruits stored at normal pressure. However, when they were stored at a high relative humidity, as high as 98% with a pressure of 190 Torr, a considerable degree of deterioration and decay occured after transfer. The ethylene and carbon dioxide production was also higher than that in fruits stored at a pressure of 190 Torr with a relative humidity of 75% or at a pressure of 760 Torr with a relative humidity of 86%.

Introduction

Effects of low pressure on the preservation of fruits and vegetables were investigated with a view to applying this technique to the storage and transportation of fruits. In our previous report using an aerated type apparatus(7), the effects of a low partial pressure of oxygen on the retardation of ripening, respiration and ethylene production in apple, peach and tomato were clearly demonstrated, but no favorable effect was found in satsuma mandarin fruit.

It has been reported(9, 10, 11) that ethylene production by fruit is retarded under storage at low pressure. However, Burg *et al.* (4) reported that ethylene production in fruit increased rapidly immediately after transfer from anerobic conditions to ambient air. For the development of practical methods of low pressure storage, the changes occurring after transfer should be understood.

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This study was undertaken in order to clarify the changes in respiration and ethylene production when fruits are released from low pressure storage. Tomato, Japanese pear and orange fruits were used as they show various respiration patterns during ripening.

Materials and Methods

1. Experimental apparatus for low pressure storage(aerated type)

The experimental apparatus for both low or normal pressure storage were improved as compared with those used in the previous report(7). The direction and rate of air flow into both apparatus are shown in Fig. 1. Pressure in the fruit chamber was reduced by using a vacuum pump and controlled by modifying the degree of valve opening. The humidifier was controlled manually depending on the indications of the hygrometer. The experimental apparatus were placed in a 5±1 °C refrigerated room.

2. Carbon dioxide and ethylene production

Fruits that had been stored at low pressure were transferred to an environment at normal pressure at weekly intervals. The sample fruits of which the weight had been determined were then kept in closed 10 *l* vessels in a refreigerated room at 3±1°C. Gas samples for carbon dioxide and ethylene analyses were collected from the closed vessels by a 2 ml pressure-lock gas syringe, with 3 replications. Carbon dioxide and ethylene concentrations were estimated by gas chromatography under the following conditions :

Column : Porapack Q80-100 mesh, glass column 3 mm×2 m. Column temperature : 74 °C. Carrier gas : He 25 ml/min. Detecter : TCD(carbon dioxide), FID(ethylene).

3. Experiment on Japanese pear fruit

Japanese pear fruits (*Pyrus serotina* Rehd. var. *culta*) cv Chōjūrō($\bar{x}$=397.1 g) were harvested on Sept. 24 th, 1982 in the orchard of the University of Tsukuba. Eight fruits were stored at 190, 285 and 760 Torr pressure in an experimental apparatus of the aerated type from Sept. 30 th to Nov. 4 th (36 days). The relative humidity was maintained at 75% for low pressure storage in this apparatus. Carbon dioxide and ethylene evolution by fruit within 3, 6, 12 and 24 hours immediately after transfer to the ambient atmosphere was studied at weekly intervals.

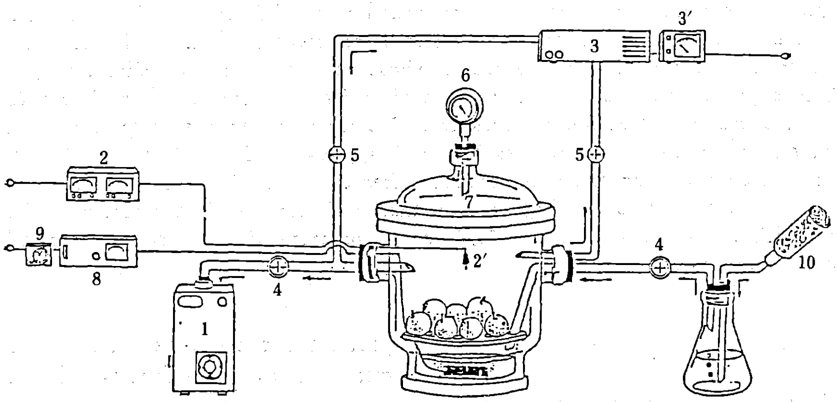

Fig. 1. Experimental apparatus used for low pressure storage(aerated type).
1. Vacuum pump (air flow rate is 50-100 ml/min.).
2. Sensitive thermometer and hygrometer (2′ : Sensor).
3. Oxygen analyzer (3′ : Meter).
4. Needle valve.
5. Valve.
6. Vacuum guage.
7. Fruit chamber (10 *l*).
8. Humidifier.
9. Timer.
10. Air filter.

The fruit characteristics including weight, firmness and specific gravity of fruit and juice quality including organic acid content, pH, specific gravity, Brix, total and reducing sugars levels were investigated before and after storage.

4. Experiment on tomato fruit

Tomato fruits(*Lycoperscion esculentum* Mill.) cv Meteryōzu($\bar{x}$=205 g) in the breaker stage of ripening were harvested on Nov. 13 th, 1982 at the tomato farm of Kukizaki, Ibaraki. Fourteen fruits were stored in the experimental apparatus of the aerated type from the time of harvest until Dec. 23 th (40 days). The relative humidity and pressure were controlled to values of 75% and 190 Torr and values of 85% and 760 Torr. Evolution of carbon dioxide and ethylene production by fruit within 3, 12 and 24 hours immediately after transfer to the ambient atmosphere was studied. The characteristics and quality of fruit were investigated in the

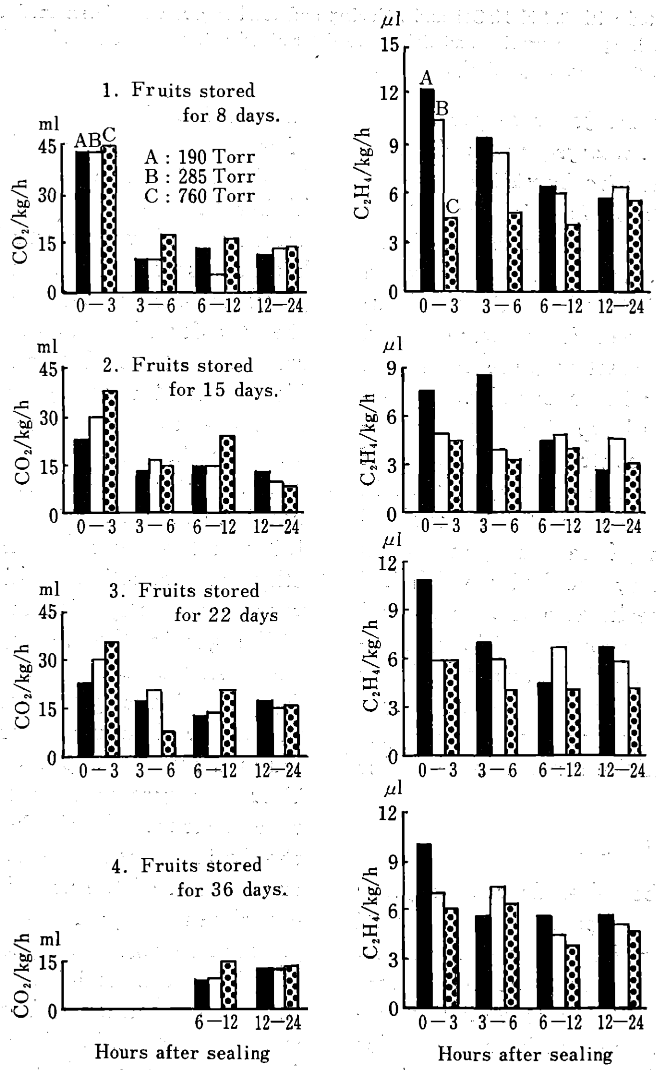

Fig. 2. Changes of carbon dioxide and ethylene production rates of Japanese pear fruits which has been stored at various pressures and transferred to ambient atmosphere at weekly intervals, shown determining the accumulation during 24 hours immediately after transfer.

Table 1. Effects of low pressure storage on the characteristics and qualities of Japanese pear fruits stored for 36 days.

Torr	Weight loss %	Firmness[z] kg	Specific gravity[y]	Fruit juice[x] Organic acid, g/100 g	pH	Specific gravity	°Brix	Reducing sugar, g/100 g	Total sugar, g/100 g
Pre-storage		1.00	1.00	0.56	4.65	1.042	9.8	7.43	14.01
190	9.08	0.95	1.01	0.55	4.60	1.048	11.7	7.70	14.53
285	6.14	0.95	0.95	0.53	4.63	1.045	9.5	6.65	12.52
760	5.01	0.96	0.99	0.55	4.64	1.042	10.8	8.02	15.14

[z] Fruit firmness was assessed by resistance to puncture with a rheometer fitted with 5 mm head.
[y] Spcific gravity of fruit was calculated as follows : Weight of fruit÷[Weight of fruit+(Weight of basket in water−Weight of fruit and basket in water)].
[x] Organic acid was titrated with 0.1 N-NaOH and reducing and total sugars were determined applying the Somogyi & Nelson's method. pH, specific gravity and Brix were determined using glass-electrode pH meter, Baumé hydrometer and digital refractometer, respectively.

same manner as for the Japanese pear.

5. *Experiment on orange fruit under various conditions of relative humidity*

Orange fruits(*Citrus sinensis* Osbeck) cv Fukuhara($\bar{x}$=152 g) were harvested on March 30 th, 1982 in the citrus orchard of Kanagawa Horticulture Experimental Station, Nebukawa branch. Eighteen fruits were stored from the time of harvest to June 29 th at a pressure of 190 Torr in an experimental apparatus of the aerated type in which the relative humidity was controlled to values of 98% or 75%. Control fruits were stored in the same type of apparatus at 760 Torr and 85%RH. Evolution of carbon dioxide and ethylene production by the fruits which had been stored for 8 weeks at a low or normal pressure and under various conditions of relative humidity was studied after the fruits were transferred to the ambient atmosphere. The characteristics, quality and decay of fruit were investigated in the same manner as for the Japanese pear.

Result

The rates of carbon dioxide and ethylene production of Japanese pear fruit within 24 hours after transfer from low and normal pressure storage to the ambient atmosphere are shown in Fig. 2. The carbon dioxide production by fruits which had been stored for 8, 15, 22 and 36 days at low pressure was lower than that of fruits stored at normal pressure, and decreased more appreciably in the fruits which had been stored at a pressure of 190 Torr. However, the evolution of ethylene by fruits which had been stored for 8, 15, 22 and 36 days at low pressure was higher than that of fruits stored at normal pressure, and was greater in the fruits which had been stored at a pressure of 190 Torr, in particular 0–3 and 3–6 hour immediately after the transfer of fruits to the ambient atmosphere. Total evolution rates of carbon dioxide within 24 hours by the fruits which had been stored at a pressure of 760 Torr did not vary significantly with the period of storage, but the rates were lower in the fruits which had been stored for 36 days at a pressure of 190 and 285 Torr. Similarly the rates of ethylene production within 24 hours did not vary significantly with the period of storage.

Changes in the quality characteristics of the Japanese pear fruits after storage for 36 days were investigated with materials used in the above determinations. Weight loss of fruits stored at a pressure of 190 and 285 Torr was greater than in direct proportion to a pressure of 760 Torr(Table 1). Thus the fruits stored at a low pressure became dry in spite of the use of a humidifier in the experimental apparatus. Under 190 Torr pressure storage, the specific gravity of fruit and Brix of fruit juice were higher than in the other treatments, but reducing and total sugars and organic acid contents of the fruit juice showed no change among the treatments.

In tomato fruit which had been stored for 40 days at a pressure of 190 and 760 Torr,

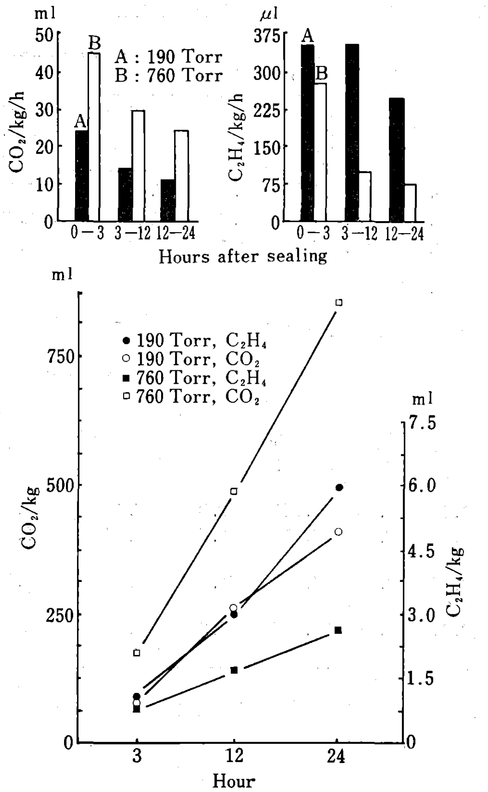

Fig. 3. Changes of carbon dioxide and ethylene production rates of tomato fruits which had been stored at 190 or 760 Torr for 40 days and transferred to ambient atmosphere. The rates was obtained by measuring the accumulation in vessels within 3, 12 and 24 hours from immediately after transfer.

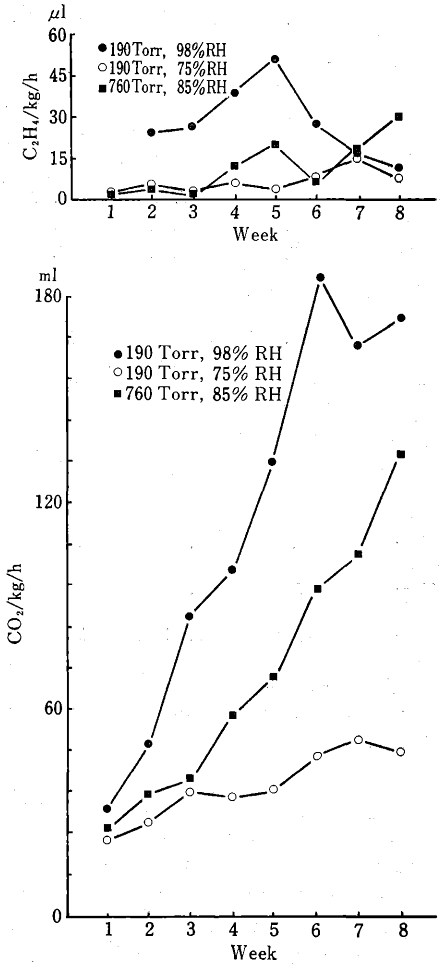

Fig. 4. Changes of carbon dioxide and ethylene production rates of orange fruits which had been stored at 190 Torr with 98%RH or 75%RH and 760 Torr with 85%RH for 8 weeks and [transferred to ambient atmosphere at weekly intervals. The rates was obtained by measuring the accumulation in vessels for 24 hours from immediately after transfer.

carbon dioxide and ethylene production rates by fruits within 24 hours immediately after transfer to the ambient atmosphere are shown in Fig. 3. In fruits which had been stored at a pressure of 190 Torr, the carbon dioxide production rate was about half the value of that of fruits stored at a pressure of 760 Torr, while carbon dioxide production rates of both decreased with on elapse of time after transfer. The ethylene production rate in fruits which had been stored at a pressure of 190 Torr, on the contrary, was higher than that at 760 Torr and remained at a high level for 24 hour after transfer. Fruits which had been stored at a pressure of 760 Torr showed a marked decrease in ethylene production after transfer.

The quality characteristics of the tomato fruits were also investigated using the same fruits as for carbon dioxide and ethylene production determination. Weight loss of fruits stored at a pressure of 190 Torr was greater than that of fruits stored at a pressure of 760 Torr, as in the case of the Japanese pear. The other characteristics of fruits did not differ between low pressure storage and normal pressure storage.

In 'Fukuhara' orange fruit with a non-climacteric respiration, changes in carbon diox-

Table 2. Effects of low pressure storage on the characteristics and qualities of tomato fruits stored for 49 days.

Torr	Weight loss %	Firmness[z] kg	Specific gravity[y]	Fruit juice[x]					
				Organic acid, g/100 g	pH	Specific gravity	°Brix	Reducing sugar, g/100 g	Total sugar, g/100 g
Pre-storage		0.57	0.98	1.44	4.3	1.024	4.7	6.13	11.52
190	17.8	0.22	1.01	1.07	4.5	1.019	4.0	6.49	12.13
760	5.0	0.20	1.00	1.04	4.5	1.026	4.5	6.34	11.92

z,y,x Same as in Table 1.

Table 3. Effects of low pressure storage on the characteristics and qualities of orange fruits stored for 13 weeks.

Torr and relative humidity	Weight loss %	Frimness[z] kg	Peel color[y]	Decay	Fruit juice[x]					
					Organic acid, g/100 g	pH	Specific gravity	°Brix	Reducing sugar, g/100 g	Total sugar, g/100 g
Pre-storage					1.50	3.80	1.051	12.0	6.40	12.40
190 Torr 75% RH	17.3	1.04	6.8	3.6	1.20	4.10	1.052	12.7	6.87	12.94
190 Torr 98% RH	7.7	1.08	7.2	7.2	1.33	4.00	1.049	12.0	7.18	13.53
760 Torr 85% RH	7.8	0.96	6.9	5.0	1.12	4.02	1.047	11.2	6.81	12.82

z,x Same as in Table 1.

y Peel color was evaluated using a "Standard color chart for orange color" issued by The Fruit Tree Research Station.

ide and ethylene production rates by the fruits in 24 hours after weekly transfer from low and normal pressures to the ambient atmosphere are shown in Fig. 4. Carbon dioxide production rates determined for 24 hours after transfer with fruits which had been stored at a pressure of 190 Torr with a relative humidity of 75% amounted to 20 ml/kg/h after one week and 48 ml/kg/h after 8 weeks of storage, showing a 2.4-fold increase during this duration of storage. The rates reached 31 ml/kg/h after one week of storage and 165–184 ml/kg/h after 6–8 weeks of storage, the increase being 5.2–6.1-fold, when the fruits were stored at a relative humidity of 98% with the same pressure. In fruits which had been stored at a pressure of 760 Torr and 85%RH the rates amounted to 24 ml/kg/h after 8 weeks of storage. Thus the effects of low pressure storage on the carbon dioxide production in orange fruits differed largely depending on relative humidity, that is, the high humidity greatly stimulated respiration whereas lower humidity suppressed respiration as compared with normal pressure storage.

While the ethylene production rates in orange fruits were lower as compared with those of tomato and Japanese pear fruits, the rates in fruits which had been stored at a pressure of 190 Torr and 98%RH were higher as compared with fruits which had been stored at lower relative humidities at both pressures of 190 and 760 Torr.

The quality characteristics after low and normal pressure storage of orange fruits were investigated in the fruit used for carbon dioxide and ethylene production determination. Weight loss of fruits stored at a pressure of 190 Torr and 75%RH was greater than that of the fruits stored at a pressure of 760 Torr with 85%RH and at a pressure of 190 Torr with 98%RH. Decay of fruits and decreases in organic acid, Brix and juice specific gravity of fruits stored at a pressure of 190 Torr with 75%RH were less pronounced than those of fruits stored at a pressure of 760 Torr. However there was an increase in the percentage of decay in fruits stored at a pressure of 190 Torr at 98%RH.

Discussion

In a previous report(7), it was shown that with apple and tomato fruits in which the respiration shows a temporary rise climacteric pattern and peach fruit in which the respiration shows a final rise pattern, the amounts of carbon dioxide and ethylene evolved in storage chambers were lower at pressures of 76–190 Torr as compared with storage at normal pressure when an aerated type apparatus was used. In particular, the ethylene production rate of fruits stored at normal pressure increased with longer storage. At low pressure the values remained small and did not change significantly with time. In addition, softening, coloring of peel and the ripening process of fruits stored at low pressure were ratarded.

We intended to clarify the effects of drastic changes in the partial pressure of oxygen after or under low pressure storage on fruit quality and the respiration and ethylene production in fruits.

Oxygen is an essential factor for ethylene biosynthesis(3). According to Burg *et al.* (4), the almost immediate cessation of ethylene production under anaerobic conditions indicates that ethylene production is in some way linked to the utilization of atmospheric oxygen. Although ethylene production and oxygen uptake show a very similar dependence upon oxygen partial pressure, it is unlikely that the correlation is mediated through energy production. Fruit tissues are unable to produce ethylene under anaerobic conditions but are able to produce ethylene aerobically after a brief exposure to oxygen. Fruit tissues preincubated at low oxygen levels produced ethylene without a lag period at a rate higher than that by control tissue preincubated in air, when exposed to a high oxygen level (air, 21% oxygen). Although the synthesis of ethylene ceases almost immediately under anaerobic conditions, a precursor accumulates which can be rapidly oxidized in air producing ethylene.

Apelbaum *et al.* (1) studied mango fruits which show a climacteric respiration which were stored for 35 days at pressures of 60, 80, 100, 200 and 760 Torr. They determined the carbon dioxide and ethylene production in fruits after to the ambient atmosphere, and showed that the climacteric peak of respiration of fruits stored at a low pressure occurred later.

In this experiment with Japanese pear fruit, the ethylene production by fruits transferred from low pressure storage to the ambient atmosphere was significantly higher than that by fruits transferred from normal pressure storage. However, the carbon dioxide production by fruits during the 24 hours immediately after the transfer from low pressure storage was lower than that of fruits stored at normal pressure. The increased ethylene production by the fruits mentioned above occurred immediately after transfer to the ambient atmosphere during the 0–6 hour period, regardless of the storage period. This increase appeared to be similar or more pronounced in tomato fruit than in Japanese pear fruit. Thus this response can be considered to be one of the characteristics of climacteric fruits. When fruits in which ethylene production had decreased almost immediately at low pressure were transferred to an environment at normal pressure, those fruits which were at the stage of the climacteric rise in respiration showed rapid increased in ethylene production.

In the case of orange fruits in which the raspiration is non-climacteric, ethylene production by orange fruits stored at a low relative humidity was lower under both low and normal pressure storages as compared with that of fruits stored at a high relative humidity. According to Oogaki and Manago (8), when the relative humidity exceeded 90 % in the CA storage, the fruit peel absorbed moisture and the increase in the moisture content induced the deterioration of fruit quality and decay. In our previous report (7), the effects of low pressure storage on the preservation of satsuma mandarin fruits were not significant and fruits stored under conditions of high relative humidity in the fruit chamber showed a pronounced deterioration in fruit quality and decay. In this experiment, orange fruits that had been stored at a low pressure with a high relative humidity showed very severe decay and produced more ethylene and carbon dioxide after transfer to the ambient atmosphere when compared with fruits stored at a low pressure with a low relative humidity and fruits stored at a normal pressure. This phenomenon may be attributed to the physiological disorder and abnormal respiratory function occurring under high humidity condition.

In the case of low pressure storage of fruits such as Japanese pear and tomato where the effects of low pressure tratment are evident regarding keeping quality, it is important to maintain an optimum regarding relative humidity in the storage chamber in order to control the increase in ethylene production by fruit after transfer to the ambinet atmosphere.

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減圧貯蔵法における減圧解除後の果実呼吸量及びエチレン生成の特長

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摘　要

収穫後の果実のエチレン生成には酸素を必要とし，果実を窒素で満たすような嫌気的条件におくと，エチレン生成は速やかに停止する．エチレン生成をとめておいた果実を空気中に戻すと，直ちにエチレン生成を開始し，その生成速度は果実を空気中にそのままおいておいたもののエチレン生成速度よりも一時的に大きな値を示すとされている．

本報告では，減圧すなわわち酸素分圧の低い条件においても，貯蔵果を常圧へ戻した時に上記と同様のエチレン生成をするかを検討したものである．一時上昇型クリマクテリック呼吸を営むニホンナシ及びトマトについて，190，285 Torr でそれぞれ36日間，40日間貯蔵した果実を，ほぼ1週間ごとに常圧に戻し，その0～3，3～6，6～12，12～24時間内の二酸化炭素とエチレンの生成量を測定した．常圧で貯蔵していた果実と比較して明らかにエチレン生成量が多く，一方呼吸量は低い傾向であった．非クリマクテリック呼吸を営むオレンジ果実は，常圧に戻した後のエチレンの生成量も呼吸量も少なかった．ニホンナシとトマト果実については，果実品質に及ぼす減圧の好影響が認められたが，オレンジは 190 Torr 下でも 98%RH のように高湿で貯蔵すると，常圧に移したあとの二酸化炭素とエチレンの生成量が，190 Torr･75%RH 及び 760 Torr･85%RH で貯蔵した場合より大きな値を示し，また変質と腐敗とが多かった．