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Influence of Intracellular Structured Water Formed by Xe Gas on the Shelf Life of Eggplant Fruit (*Solanum melongena* L.)

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Abstract: Formation of structured water by dissolution of non-polar gas increases the viscosity of water and results in suppression of metabolic activity due to the resultant low rate of enzymic reaction. This phenomenon was applied to extend the storage life of eggplant fruits using Xe gas. Two combinations of temperatures and partial pressures of Xe were investigated. The respiration rates in Xe treated samples were found to be 10.1 and 11.9 $mgCO_2 kg^{-1} h^{-1}$, for 10 and 15°C, respectively and were less than those of control. The Xe treated samples showed a lower respiration rate. The calyx was not deteriorated and flesh browning was not observed. Weight loss did not differ significantly, however lower in the treated sample. Therefore, the Xe treatment was found to be effective for extending the storage life of eggplant fruits.

Key words: Eggplant, storage, viscosity, structured water, calyx, respiration, browning

Introduction

Postharvest loss of fresh fruits and vegetables range from 5 to 25% in the developed countries and 20 to 50% in the developing countries (Kader, 1992). These losses include the physiological and chemical deterioration of fresh products caused by high respiration rate, ethylene biosynthesis, decomposition, loss of nutrients, physical injuries and/or microbial actions (Kader, 1986). Storage methods are applied to maintain food quality and reduce the losses. In conventional storage methods, low temperature is used to reduce the metabolic activity of fresh product, maintain their quality and give a longer shelf life. However, storage is restricted because the temperature cannot be lowered below a limit, where freezing or chilling injury (CI) may occur. Chemical control cannot be used to prevent browning in uncut fruits and vegetables and it has also health hazards (Whitaker and Lee, 1995).

The eggplant (*Solanum melongena* L.) is popular throughout the world and is grown in tropical or semitropical climates (Esteban *et al.*, 1989). Due to its tropical origin, it is susceptible to CI when stored below 10 °C. The sensitivity of the eggplant fruit to CI varies with variety, maturity, size of the fruit, and season of harvest (Salunkhe and Kadam, 1998). Marketing and storage of perishable commodities is generally conducted at 5 °C, which can cause CI in eggplant fruits (Munoz-Delgado, 1985; Nothmann, 1986). Risse and Miller (1983) reported that eggplants stem and calyx turned from green to brown more rapidly with covered mold growth during storage at 16 °C. Abe *et al.* (1980) reported that when eggplants were stored at 20 °C, wilting and decay of the calyx were the main causes of its deterioration.

Research and development efforts are continuously aimed at improving the existing technology and testing new ideas and hypothesis for possible alternative to the current techniques. The non-polar or inert gases (Helium, Neon, Argon, Krypton and Xenon) have low chemical reactivity and these gases do not induce harmful biochemical changes in cells. Tanaka and Nakanishi (1991) reported, that when Xe was dissolved into water, a large number of hydrogen-bonded water molecules are formed by a hydrophobic interaction and the water in this state is termed as "structured". The number of hydrogen-bonded water molecules is one of the factors governing the motion of water molecules. The viscosity of water is expected to be increased when the number of hydrogen-bonded water molecules increases. When the intracellular water of fresh products becomes structured, metabolic activities are thought to be suppressed by reduction in the diffusion rate of substrate, which may prolong the postharvest storage life (Oshita *et al.*, 1997a). Non-polar gases and gas hydrates have been studied in the field of chemistry (Rao *et al.*, 1992) and physiology (Nakata *et al.*, 1997). Little is known about the use of these gases in postharvest technology. Among the inert gases, Xe possesses the greater capacity to form the structured water within the fruits (Oshita *et al.*, 1997a). A series of experiments have been carried out using Xe gas for storage of: rose (Oshita *et al.*, 1995); carnation (Oshita *et al.*, 1996) and broccoli (Oshita *et al.*, 1997b). The aim of the present work was to study the metabolic and enzymic activity of eggplant due to the formation of structured water by applying Xe gas and to investigate the storage period. The effects of structured water by Xe in eggplant fruits were evaluated by measuring: evolved CO_2, weight loss, ageing of calyx, flesh colour and browning.

Materials and Methods

Eggplant fruits (*Solanum melongena* L. white variety) were obtained from the experimental farm of the University of Tokyo during July and September, 1995. Within 2 hrs of harvest, the fruits were transported to laboratory of Bioprocess Engineering at the University of Tokyo, Japan and temporarily stored in a room at controlled temperature of 15°C for 2 days before measurement. The eggplant fruits were selected such that these were: almost equal in size; similar in colour; and free from disease. The fruits were weighed on an electronic balance. Two combinations of temperature and pressure (10°C/0.29MPa and 15°C/0.39MPa) were employed (Table 1). The temperatures were selected to avoid CI and to give higher solubility of Xe gas. The samples were placed inside a steel container having an inner volume of 2.12 L (diameter of $130x10^{-3}$ m and a height of $160x10^{-3}$ m). The lid of the container was immediately closed. For each treatment, two containers were used. One of these containers was pressurized with Xe and the others acted as control. The pressurization process was started at room temperature and was completed within few minutes. The containers were kept in constant temperature chambers at 10 and 15 °C for

Table 1: Experimental conditions

Temp. (°C)	Xenon		Control
	Pressure (MPA)	Solubility (mole-Xe/mole-H_2O)	Pressure (MPa)
10	0.29	3.613×10^{-4}	Air: 0.10
15	0.39	4.122×10^{-4}	Air: 0.10

Table 2: Changes in Xe partial pressure and amount of Xe dissolved in eggplant

Temp. (°C)	Measured pressure (MPa)			
	Initial*	Final	Difference	Xe concentration in eggplant (mole-Xe/mole-H_2O)
10	0.29	0.25	0.04	3.66×10^{-3}
15	0.39	0.37	0.02	1.72×10^{-3}

*Initial pressure was measured at 20 °C

Table 3: Changes in sample mass and weight loss of eggplant

Sample mass, $\times10^{-3}$ kg					
Xenon condition			Control condition		
Initial	Final	Loss (%)	Initial	Final	Loss (%)
86.19	86.06	0.13 (0.15)	91.78	91.39	0.39 (0.42)
94.98	94.98	0.00	95.38	94.94	0.44 (0.46)

Parenthesis indicates weight loss in percentage

two weeks. Gas chromatograph (GC-14A, Shimadzu Co., Japan) was used to measure the CO_2 concentration. The sample of 1mL was drawn from the containers with the help of gas syringe and was adjusted to 0.5mL before injecting into a GC, fitted with a thermal conductivity detector at 100 °C. The flow rate for the carrier gas of helium was 30mL min^{-1}. The partial pressure of CO_2 (PCO_2) and cumulative quantity of evolved CO_2 (CQEC) were calculated as mentioned by Oshita *et al.* (1997b). Inner pressure (kg cm^{-2}) of the sample container was measured by pressure monitor (PM 222, GL Science). To calculate the amount of Xe dissolved in sample, the water content of fruit was considered approximately 93%. The weight loss of the sample was determined from difference between the weights of fruits before and after storage and expressed as a percentage. The colour of calyx and flesh were compared through photographs at the end of the storage. Linear regression curves were fitted to CQEC data and respiration rates were determined from the slopes of these regression lines.

Results and Discussion

Partial pressure and amount of Xe dissolved: The partial pressures of CO_2 (PCO_2) in Xe containers were less than the control at 10 and 15 °C due to the suppression of CO_2 production (Fig. 1 and 2). It showed that the difference in partial pressure of CO_2 was not significantly different in treated samples between 10 and 15°C, while it differed in the control at these two temperatures. Table 2 showed that the partial pressure of Xe gas (P_{Xe}) was reduced for both the temperatures. The difference between the initial and final partial pressure of Xe was 0.04MPa and 0.02MPa for 10 and 15 °C, respectively. According to Oshita *et al.* (1997a), this is due to the dissolution of Xe gas into the intracellular water of the eggplant fruits. Table 2 also shows that the amount of Xe gas dissolution was higher at 10 °C than at 15°C due to the difference in P_{Xe}. The greater reduction in P_{Xe} at 10 °C was probably due to the lower temperature.

The difference in the amount of Xe solubility in pure water is not large between the two combinations of temperature and

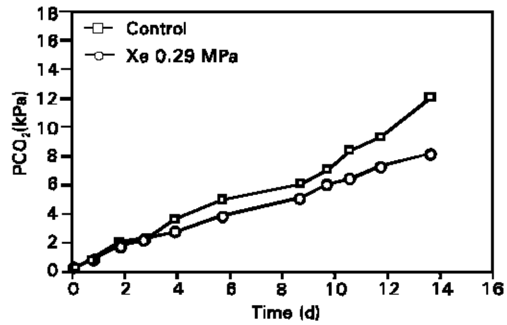

Fig. 1: Changes in partial pressure of CO_2 (PCO_2) during storage of eggplant at 10°C.

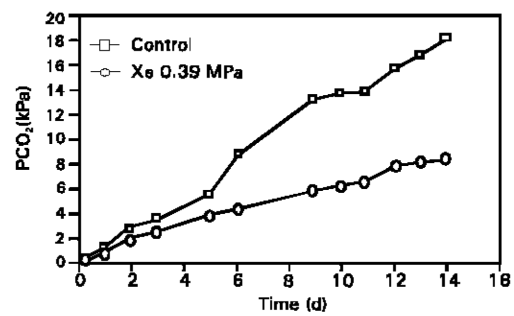

Fig. 2: Changes in partial pressure of CO_2 (PCO_2) during storage of eggplant at 15°C.

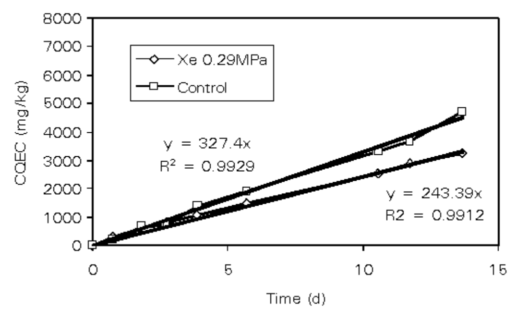

Fig. 3: Changes in CQEC during storage of eggplant fruits at 10 °C.

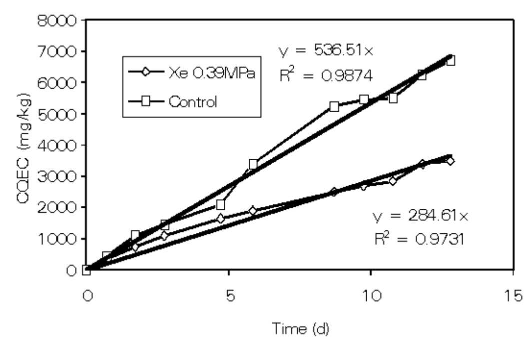

Fig. 4: Changes in CQEC during storage of eggplant fruits at 10°C.

Fig. 5: Calyx colour of eggplant changes after 2- weeks of storage at 15 °C.

Fig. 6: Flesh colour of eggplant changes after 2 -weeks of storage at 15 °C.

pressure for test -1 and 2 (Table 1). Therefore it can be easily understood from the combination effect of temperature and pressure conditions of Xe on eggplant, the greater reduction in Xe partial pressure was due to the lower temperature (10 °C) than the higher temperature (15 °C). The results indicated that the solubility of Xe gas depends upon the combination of temperature and pressure.

Cumulative quantity of evolved CO_2 (CQEC): Cumulative quantity of evolved CO_2 in the Xe treated sample and in control at 10 and 15 °C are plotted in Fig. 3 and 4, respectively. The CQEC was higher in control samples than in Xe treated samples for 10 and 15 °C. In the control sample, the CQEC value was quite high (6694 CO_2 mg kg^{-1}) at 15 °C than (4715mg CO_2 kg^{-1}) at 10 °C at the end of the storage. Similar observation was recorded for Xe treated samples, where the CQEC value was higher at 15 °C (3501 CO_2 mg kg^{-1}) than at 10 °C (3235 CO_2 mg kg^{-1}) at the termination of the storage. The difference of CQEC between the Xe treated samples at 10 °C and 15 °C was not large. The lower value of CQEC in Xe treated sample as compared with the controls indicated the reduction in respiratory activity, due to the formation of structured water (Oshita *et al.*, 1997a).

Respiration rate: Carbon dioxide concentrations in excess of 7% can deteriorate the eggplant fruits (Viraktamath, 1993). Hence, a safe limit of 5% was taken and calculations of respiration rates were made, when the PCO_2 reaches 5kPa (Figs. 1 and 2). It was found that safe limit reached on 6th day at 10 °C, and for the 4th day at 15 °C. At 10 °C, the respiration rates were 10.1 mgCO_2 kg^{-1} h^{-1} in the Xe treated sample (y = 243.39x, R^2 =0.9912) and 13.6 mgCO_2 kg^{-1} h^{-1} in the control sample (y = 327.4x, R^2 =0.9929). At 15 °C, respiration rates were 11.9 mgCO_2 kg^{-1} h^{-1} in the Xe treated sample (y = 284.61x, R^2 =0.9731) and 22.4 mgCO_2 kg^{-1} h^{-1} in the control (y = 536.51x, R^2 =0.9874). The respiration rate of Xe treated eggplants were 26 and 47% lower than that in controls for 10 and 15 °C respectively. The results indicated that respiratory activity in Xe treated groups was suppressed, as expected from the structurization of water reported by Oshita *et al.* (1996). The respiration rate of 13.6 mgCO_2 kg^{-1} h^{-1} for the control sample from this study compared well with the value of 13 mgCO_2 kg^{-1} h^{-1} at 10 °C as reported by Burzo *et al.* (1994).

Weight loss: Table 3 shows that the weight loss was observed to be less than 1% in all the treatments after the end of storage. At both temperatures, about 0.4% weight loss was obtained in the control samples, while the Xe treated sample had values lower than this. This low weight loss is attributed to high RH (Risse and Miller, 1983). Campbell *et al.* (1997) mentioned that hydrogen bonds decreased the tendency of water molecules to evaporate. It is thought that Xe gas formed a large number of hydrogen bonded water molecules by the hydrophobic interaction, and consequently Xe atoms hold the water molecules in place, which in turn prevent weight loss due to evaporation from the stored fruits.

Calyx colour: The freshness of the calyx in eggplant fruit is an important aspect of its quality. The control sample was deteriorated and senescence was observed at 15 °C (Fig. 5). On the other hand, the calyx colour of Xe treated sample remained similar throughout the storage period. By contrast, at 10 °C, profound difference was not detected between the treated and control samples (data not shown). The quality of the Xe treated samples was better than controls. Eggplant fruits deteriorated during prolonged storage, mainly due to senescence of the stem and calyx (Temkin-Gorodeiski *et al.*, 1993). The results showed that use of Xe proved to be effective in not only controlling the weight loss but also preserving the calyx colour. The formation of structured water might be helpful in the retention of calyx colour.

Flesh colour: Chilling injury was not observed for Xe-treated and control samples stored at 10 °C. Flesh browning was occurred in control sample at 10 °C, while Xe treated sample remained fresh. At 15 °C, the control sample showed white to light brown colour. The Xe treated sample retained it's initial colour throughout the storage period at the same temperature (Fig. 6). It was also observed that the portions, where the browning was evident, had decayed. This indicated that high CO_2 production was evolved in control fruits (Mencarelli *et al.*, 1991). The suppression in browning depends on several factors including nature of fresh products, temperature and chemicals (Izumi *et al.*, 1996). Aluko and Ogbadu (1986) reported that the catalase enzyme activity in white eggplant was higher than other varieties. This enzyme catalyzed the decomposition of hydrogen peroxide and caused the acceleration of senescence in fruits (Brennan and Frenkel, 1977). Esteban *et al.* (1989) stated that the increase in total polyphenol content at 5, 10 and 20 °C might be the cause of browning mechanism after 4 days of storage. Application of Xe gas suppressed the browning at the cut surfaces of broccoli (Oshita *et al.*, 1997b). Dodds (1991) suggested that temperature above chilling sensitivity and high RH prevent the CI in the solanaceous fruits, tomato and cucumber.

Overall the Xe treated samples were found better than that of the control sample. Xenon helped in suppressing the metabolic activity and in maintaining the colour. Application of Xe extended the storage life of eggplant fruits for about two weeks. Therefore, the Xe treatment may be considered as a new method for the storage of fresh fruits and vegetables.

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