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Effect of the Storage Temperature, Duration and Gamma Irradiation on the Respiration Rate and Sugar Content of Minituber 'Superior'

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ABSTRACT : This study was to evaluate whether ionizing gamma radiation could be applied to break the dormancy of a potato minituber. The respiration rate of the minitubers was significantly affected by the storage temperature and a low dose gamma radiation. Ionizing radiation of 8 Gy enhanced the respiration rate of the potato tuber stored at 10℃ for 20 days. The potato tuber subjected to 4 and 8 Gy after 40 days storage at 10 and 20℃ exhibited higher respiration rates compared to the control (non-irradiated), but not at 5℃. However, the ionizing radiation did not exhibit on significant effect on the respiration rate of the potato tuber stored for 60 days. It was observed that minitubers stored for 20 days had significant response to the storage temperature in terms of the total sugar content the higher the storage temperature, the lower the total sugar content. It was measured that the reducing sugar content was increased under the storage conditions both 5 and 10℃ for 40 days, but not to 20℃. The total sugar contents in the minituber stored for 60 days were similar to those stored for 40 days. The data was discussed on the relationships among the storage duration, temperature and ionizing radiation.

Key words: potato, minituber, total sugar content, respiration, ionizing radiation

INTRODUCTION

Living organisms have been evolved via interaction with an environment of natural radiation. Gamma radiation is one of the environments surrounding living organisms. Numerous ionizing radiation-induced effects have been studied on a variety of animals and plants. For example, a high dose of ionizing radiation has been shown to considerably affect the morphological and physiological phenomena including cell wall and membrane formation, protein synthesis[1,2)], enzyme activity[3)], ethylene synthesis and respiration rate[4)]. In agriculture, the high doses of gamma radiation are used as the seed insecticide and agent for mutation breeding. However, relatively few studies have been done to investigate the effects of a low dose gamma irradiation on plants.

It was suggested that agents which are harmful at high concentration could stimulate the biological activity at a low level, which is called "radiation hormesis"[5)]. The ionizing radiation at a low level such as x- and gamma-rays was also suggested as an agent to stimulate the biological activities, leading to an improved germination, early seedling and increased crop production[6,7,8)]. It is reported that low doses of irradiation for seeds or young plants often resulted in an increased germination, growth rate, length of flowering stage, rooting ability and fruit productivity[5)]. In addition, there are various physiological and biochemical stimulatory effects of a low dose ionizing radiation; increased photosynthesis and nucleic acid synthesis of carrot[9)], improved photosynthesis of corn[10)], increased respiration and catalase activity of mustard[11)].

It is known that harvested potato tubers have an internal dormancy preventing sprout growth from occurring in environmentally favorable conditions[12)], probably demanding

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hormetic or stimulatory agents to break the potato tuber dormancy to initiate sprouting at an appropriate time. This study aimed to investigate whether ionizing radiation, suggested as a hormetic factor[13], could be used as an agent to break the dormancy of the potato minituber grown from the microtuber through examining the radiation-induced changes in the respiration rate and sugar accumulation of the dormant potato minituber 'Superior' stored under different storage temperatures and durations.

MATERIALS and METHODS

Potato microtuber 'Superior' (*Solanum tuberosum* L.) was provided by Korea Research Institute of Bioscience and Biotechnology (KRIBB) and cultivated to the minituber in the greenhouse for 3 months. The minitubers were dark-stored at 5, 10 and 20℃after harvest. The minitubers stored for 20, 40 and 60 days at each storage temperature were gamma-irradiated with doses of 4 and 8 Gy generated by a gamma irradiator (^{60}Co, ca. 150 TBq of capacity, AECL) at Korea Atomic Energy Research Institute (KAERI). Dose rate was 2 Gy hr^{-1}. Radiation doses used in this study were low enough so that the minitubers did not exhibit any visible damages during the experiment (data not shown).

The respiration rate of the irradiated minitubers was measured at day 0, 20 and 40 after irradiation. The irradiated minitubers were stored in light at 20℃ before the respiration measurements. The minitubers (80-120g) in the plastic box (1200mL/box) were transferred to a growth chamber at 20℃ and the gas was collected from the box after 2 hours. The sampled gas (1ml/box) was injected and CO_2 concentration in the gas was analysed by a gas chromatograph (Shimadzu GC-14B, Japan). The contents of sucrose, glucose and fructose in the minituber samples (2g/treatment) were analysed by a sucrose/glucose/fructose combination kit (BM Cat. No. 716260, Boehringer Mannheim Chemica) according to the manufacturer's instructions. Total sugar content was calculated as a sum of the sucrose, glucose and fructose.

RESULTS AND DISCUSSION

In a state of dormancy potato tubers are still metabolically active, which is closely associated with respiration and is required for cell maintenance[14]. Respiration rate generally falls from a high value at harvest to a much lower basal level within a few weeks and the time taken for this fall depends on the temperature[15] and probably on the cultivar, tuber maturity and previous field conditions as well. Following this initial decrease, respiratory activity during storage at a constant temperature shows little changes with time until sprouting begins, when there is an increase in the respiration rate[16].

Table 1. Response of the respiration rate of the minitubers to a low dose gamma irradiation stored for 20, 40 and 60 days after harvest.

Storage duration (days)	Temperature (℃)	Dose (Gy)	Respiration rate (CO_2·ml/kg/h) 0 DAI*	20 DAI	40 DAI
20	20	0	13.4±0.26	20.2±0.29	23.9±1.05
		4	14.9±0.28	19.2±0.17	17.7±0.16
		8	17.4±0.51	20.4±0.14	17.4±0.67
	10	0	26.2±0.28	17.8±0.38	18.1±0.66
		4	26.8±0.24	19.6±0.06	18.8±0.09
		8	37.4±0.69	18.9±0.41	25.6±0.73
	5	0	44.1±0.18	23.1±0.20	18.1±0.14
		4	41.1±0.75	19.7±0.47	22.8±0.96
		8	41.9±1.57	17.4±0.28	20.3±0.11
40	20	0	35.2±0.52	23.3±0.37	19.8±0.33
		4	40.6±0.57	23.8±0.03	19.5±0.21
		8	43.8±2.38	23.1±0.20	22.3±0.20
	10	0	31.7±0.61	23.7±1.18	26.2±0.20
		4	41.3±0.88	18.8±0.37	20.7±0.33
		8	45.6±0.53	18.1±0.22	24.5±0.12
	5	0	45.1±1.75	21.7±0.56	19.5±0.47
		4	35.2±0.52	23.3±0.37	19.8±0.33
		8	40.6±0.57	23.8±0.03	19.5±0.21
60	20	0	16.0±0.37	30.9±0.05	17.8±0.23
		4	21.8±0.23	34.4±0.51	21.4±0.56
		8	20.7±0.29	33.3±0.40	21.2±0.14
	10	0	25.5±1.06	29.6±1.40	21.3±0.17
		4	28.8±0.32	22.3±2.42	21.2±0.29
		8	29.4±0.39	25.4±0.12	24.5±0.21
	5	0	34.5±0.36	24.2±0.26	22.8±0.37
		4	41.3±0.81	20.5±0.21	27.1±0.33
		8	42.5±0.61	21.0±0.74	27.1±0.20

* DAI; Days after irradiation.

The respiration rate of minitubers irradiated after 20 days storage at each temperature showed temperature- and irradiation-dependent responses, respectively. The lower storage temperature induced the lower respiration rate (Table 1). Compared to the control, irradiation with 8 Gy increased the respiration rate of the minitubers stored at both 10 and 20℃ although it was not true for those at 5℃ storage temperature (Table 1). This irradiation-induced positive effect on the respiration rates of potato tuber were also shown in a study by Jeon *et al.*[17]; the respiration rate increased by a maximum 7 fold for 2 days storage after irradiation although it was normalized thereafter. In addition, the respiration rate of the minitubers further stored for 20 and 40 days after gamma irradiation decreased, respectively, compared to those measured just after irradiation (Table 1).

The minitubers after 40 days storage exhibited an increased response for the respiration rate to gamma irradiation at both 10 and 20℃ storage temperatures, but not at 5℃ (Table 1). However, the minitubers further stored for 20 and 40 days after irradiation showed decreased respiration rates compared to those measured just after irradiation, irrespective of the storage temperature (Table 1). In addition no positive effects of irradiation were found on the respiration rate of those further stored for 20 and 40 days after irradiation (Table 1).

The respiration rate of the minitubers after 60 days storage at each temperature showed similar responses to the gamma irradiation for those measured after 20 days storage at each temperature (Table 1). It seems that the respiration activity of the minitubers, which is prerequisite for initiating sprouting, is mainly dependent on storage temperature although gamma irradiation has some stimulating effects on the respiration rate, particularly at 10 and 20℃ storage temperatures and the early stage of the storage period.

Burton and Hartsman[15] and others have identified three mechanisms for sugar accumulation: low temperature sweetening, sugar accumulation associated with sprouting, and senescent sweetening. Low temperature sweetening may occur during innate and enforced dormancy, while sugar accumulation during sprouting or senescence obviously occurs only during and after enforced dormancy. Reducing sugar accumulation induced by a low temperature can be reversed by increasing the storage temperature for short periods to between 10℃ and 20℃[18].

Total sugar contents of the minitubers stored for 20 days after harvest exhibited storage temperature-dependent responses; the lower the temperature, the higher the total sugar contents (Table 2). The increase in the sugar contents at a low storage temperature shown in this study is known to be caused by the conversion of starch to sugar[19], and the amount of sugars formed depends on the varieties, maturities and pre-storage conditions as well as the temperature[20,21]. However, gamma irradiation was unlikely to affect the total sugar contents in the minitubers, irrespective of the storage temperature (Table 2).

For the minitubers stored for 40 days after harvest, the total sugar contents considerably decreased at 5℃ storage temperature compared to those stored for 20 days after harvest, but this was not observed at 10 and 20℃ storage temperatures (Table 2). Also, in a comparison with those

Table 2. Sugar contents (mg/100g F.W.) of the minitubers with a low dose gamma irradiation at 20, 40 and 60 days after harvest.

Storage duration (days)	Temperature (℃)	Dose (Gy)	Sucrose	Glucose	Fructose	Total sugar
20	20	0	8.95±1.67	5.51±0.57	2.18±0.17	16.64
		4	8.13±0.90	5.21±0.53	2.96±0.27	16.30
		8	8.58±1.17	5.63±0.19	2.62±0.11	16.83
	10	0	12.4±0.86	5.81±0.07	4.66±0.17	22.85
		4	8.83±0.47	5.96±0.25	2.26±0.17	17.05
		8	15.1±2.38	5.49±0.13	2.15±0.11	22.76
	5	0	37.4±0.20	13.2±0.07	13.5±0.02	64.17
		4	23.6±1.44	14.9±0.44	13.2±0.34	71.79
		8	25.0±3.35	18.8±0.43	15.7±1.37	59.55
40	20	0	11.2±0.49	1.21±0.19	0.78±0.14	13.2
		4	7.86±0.60	1.14±0.08	0.59±0.05	9.59
		8	9.10±0.36	0.60±0.01	0.43±0.03	10.1
	10	0	7.63±2.48	9.89±1.05	7.23±0.92	24.7
		4	6.84±1.47	9.93±0.10	5.86±0.13	22.6
		8	7.40±1.01	7.54±0.27	5.35±0.18	20.2
	5	0	9.03±0.55	11.76±0.75	12.38±0.49	33.1
		4	13.19±0.81	13.32±0.53	14.63±0.57	41.1
		8	10.40±1.47	15.75±1.18	18.99±1.10	45.1
60	20	0	5.41±0.89	3.63±0.26	3.16±0.28	13.3
		4	5.95±0.39	3.59±0.09	3.55±0.14	13.0
		8	4.41±0.09	3.05±0.08	3.04±0.16	11.4
	10	0	9.58±0.99	2.98±0.59	3.40±0.20	15.9
		4	9.12±1.02	3.76±0.24	3.42±0.11	16.3
		8	8.70±2.40	3.35±1.89	3.49±0.94	15.5
	5	0	11.9±1.74	11.68±0.88	8.37±1.47	31.9
		4	11.8±0.24	11.26±0.28	6.98±0.57	30.0
		8	11.1±0.45	9.26±0.28	8.14±0.71	28.5

stored for 20 days after harvest, the reducing sugars (glucose and fructose in this study) significantly decreased at 20℃, but not at both 5 and 10℃ storage temperatures (Table 2). Unfortunately, gamma irradiation did not influence the sugar contents of the minitubers stored for 40 days after harvest as shown in those stored for 20 days after harvest (Table 2).

As a whole, it seems that the reduction in the total sugar content of the minitubers stored for 40 days after harvest at a low temperature in this study may be attributed to a decrease in the sucrose content rather than the reducing sugars. It has been known that reducing and non-reducing sugar accumulation increases with a decreasing storage temperature below 10℃, and the rate increases rapidly below about 7℃[15]. However, it was not true for the minitubers stored for 40 days after harvest and it is likely that the effects of the storage temperature on the sugar contents might be outweighed by those of the storage duration. For the minitubers stored for 60 days after harvest, the total sugar contents did not significantly differ from those stored for 40 days after harvest (Table 2). However, the relative proportions of the reducing and non-reducing sugar to the total sugar was altered to some extent with the storage temperature, although it was not statistically significant (Table 2).

CONCLUSIONS

Minitubers 'Superior' showed a transient increase in the respiration rates after gamma irradiation, but steadily decreased to the control (non-irradiated) levels during storage. It is suggested that the artificial shortening of the internal dormancy period or dormancy breaking of the minitubers through an irradiation-induced activation of the respiration rate might demand alternatives. Furthermore, it was noted that the sugar content and the relative proportion of the reducing and non-reducing sugar in the minitubers were affected more by the storage temperature and storage duration than by gamma irradiation.

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