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Effects of Ionizing Radiation on Sprout Inhibition and Nutritive Value of Potato Tubers

by

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放射線 照射가 감자 塊莖의 萠芽抑制 및 營養價에 미치는 影響

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Abstract

Effects of various dosages of gamma ray ranging from 0 to 16 krad on sprout inhibition and nutritive value of potato tubers were investigated with Irish Cobbler variety. Sprout growth was gradually suppressed with increasing dosage, and completely inhibited with 16 krad treatment. Under this optimum dosage, weight loss of tubers was markedly reduced and tubers kept firm throughout the 2 month storage period.

Irradiation had no adverse effects on the cooking quality of potato tubers. Moisture content of stored potato tubers was shown to be in inverse proportion to sprout growth. Tubers treated with 16 krad tended to contain somewhat higher percentage of total carbohydrate than those treated with lower dosages. Significantly larger amounts of ascorbic acid were retained in 8 and 16 krad treatments than in 0 and 2 krad treatments.

Introduction

Sprout control has been recognized as the most important factor to extend storage life of potato tubers, and various sprout inhibitors including irradiation have received considerable attention. Since Sparrow and Christensen[1] in 1954 first noticed that certain dosages of gamma ray resulted in excellent sprout control of potato tubers, effect of ionizing radiation on sprout inhibition of potato tubers was investigated by numerous workers.[2~10]

It was shown that sprout inhibition could be attained with most varieties between 5 and 10 krads, and deleterious side effects were minimized at these low dosages of irradiation.[11] Bulk of data concerning the effect of ionizing radiation on the carbohydrate content [5,7,12,13] and some on ascorbic acid [4,5,13,14] are available, however, systematic data on nutritive value of irradiated tubers are lacking.

The present experiment was undertaken to determine the effect of various dosages of gamma ray on sprout inhibition with Korean commericial variety, and to evaluate cooking quality and food composition of irradiated tubers.

Materials and Methods

The potatoes employed in this study were Irish cobbler which were grown at Alpine Experiment

Station during late growing season in 1970. Harvested potatoes were shipped to this laboratory the first part of November and stored at 5°C and about 90% relative humidity for 4½ months.

It was not feasible to start experiment at the termination of rest period of potato tubers, as expected, because of delayed dosimetry of newly introduced irradiator (25,000 Ci). However, the dosimetry result revealed that new irradiator was not adequate for our experimental purpose, since there was great variation of dose rate at various positions of small containers.

Accordingly irradiation of potatoes was done with 520 Ci gamma ray at Atomic Energy Research Institute from March 16 to 17, 1971. Effort was made to eliminate possible confounding effect of dosage and dose rate. Dose rate ranged from 551 to 2,010 rad/hour. For irradiation, uniform sized potatoes were selected and equally distributed to different treatments in respective replication. A randomized complete block design with 4 replications was employed and there were 20 tubers in each plot.

Immediately after irradiation, individual tuber was weighed and its fresh weight was recorded. Then the potatoes were stored in the dark at room temperature for 2 months. At the end of storage period, each tuber was reweighed. Sprout weight and all following analytical values were expressed as quantities per original fresh weight. Tuber firmness was measured by Universal Hardness meter (Model 166-B, Kiya Seisakusho, Ltd., Japan). Percentage figures for weight loss were converted to degrees by the arcsin transformation.

For organoleptic test, potatoes were steamed at 120°C and 15 psi for 20 minutes, and then peeled. The cooked potatoes were rated using a scale of 1~5, where 5= excellent; 4=good; 3=fair; 2=poor; 1=unusable. Potatoes which had been stored at 5°C were provided as standard and rated at 3. Then all samples were compared with this standard. The color evaluation mainly considered black spot incidence, after cooking darkening, and greening. In texture rating, mealy potatoes were more highly scored than soggy one. Flavor evaluation was largely concerned with off-flavor or irradiation odor. All organoleptic tests were replicated 10 times.

In proximate composition, carbohydrate content was calculated by converting total hydrolyzed sugar into starch content (multiplied by factor 0.9) and adding crude fiber. Contents of moisture, total sugar, protein, fat, ash and crude fiber were determined by A.O.A.C. method.[15]

In mineral content, calcium was assayed with residual ash by micromethod of A.O.A.C.[15]. For other mineral determination, sample was dried at 75°C oven for 48 hours, and ground in mortar. Then 2 g of oven dry sample was weighed out and placed in 50 ml Kjeldahl flask. After adding about 15 ml conc. nitric acid, the acid and sample were mixed and heated gently so that copious fumes of nitric oxides were given off. When foaming was ceased and there were less fumes, the heat was raised till the acid was boiling. Then 3 ml of 70% perchloric acid was added to dark yellow solution of which all organic matter had disappeared, as it aids to raise the boiling point and to form a colorless digest. When the digest was clear, it was cooled and diluted with 30 ml deionized water. The diluted digest was heated till boiling and then filtered into a 100 ml volumetric flask, washing the filter paper with hot water. Phosphorus was determined by vanado-molybdate method[16] and iron by ortho-phenanthroline method,[17] using the above clear digest.

Thiamine was assayed by thiochrome fluorescence measurement[15] and riboflavin by fluorcmetric method.[15] A.O.A.C. chemical method[15] was employed for niacin assay and indophenol method[15] for ascorbic acid assay. All spectrophotometric determination was performed by Beckman DU-2 spectrophotometer and fluorescence was measured using its fluorescence attachment. All analyses were repeated 2 to 3 times.

Results and Discussion

Fig. 1 shows sprouting pattern of potato tubers treated with various dosages of gamma ray. In untreated potatoes, sprouting reached approximately 120 g per kg tuber weight within 2 months at room temperature. However, sprout growth was considerably reduced even if potatoes were exposed to extremely low dosage such as 2 krad. Sprouting was greatly decreased at 4 krad and almost completely suppressed at 8 krad. No measurable amount of sprout growth was produced on potato tubers treated with 16 krad.

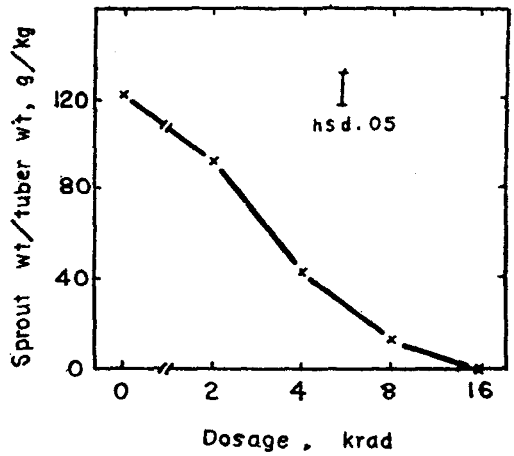

Fig. 1. Effect of various dosages of gamma ray on sprout inhibition of potato tubers stored at room temperature. Bracket indicates honestly significant difference at 5% level by Tukey's procedure

It has been well recognized that optimum dosage of gamma ray for sprout inhibition of potato tubers ranges from 5 to 10 krad depending on the variety.[11] However, in the present experiment, 8 krad failed to control sprout growth completely. This might be partially attributable to extremely low dose rate, varietal difference, irradiation time, or storage condition.

In general, it is assumed that some of the initial radiation damage would be repaired before sufficient injury to produce death had been accumulated. Thus an extension of exposure time would result in less effective damage, even though total energy transfer was equal. As the exposure time is increased furthur, greater recovery of early damage would occur before end of irradiation. In the present study, potatoes were exposed to gamma ray for 4 hours to obtain 8 krad treatment, and such extremely low dose rate might have led irradiated potato eyes to partial recovery.

It appears that irradiation dosages for effective sprout inhibition might be different depending on the variety at constant storage temperature. According to Workman et al.,[18] Red Pontiac required somewhat higher dosage than Sebago, Russet Burbank and Katahdin respectively at 5°C and 13°C storage temperatures. In this work, potatoes from different localities were used.

Concerning irradiation time for sprout control of potato tubers, Hendel and Burr[3] reported that delay between harvest and irradiation did not affect sprout inhibition. Temperature is considered to be one of the most important storage conditions in prolonging storage life of potato tubers, and higher dosage of gamma ray seems required for sprout inhibition of potato tubers at higher stroge temperature than at lower storage temperature. Previous workers[18] pointed out that Sebago, Russet Burbank and Katahdin required 5.0 kilorep at 5°C and 7.5 kilorep at 13°C for complete sprout inhibition, while Red Pontiac required 7.5 kilorep at 5°C and 12.5 kilorep at 13°C. Throughout the present investigation, potatoes were stored at room temperature which ranges from 23°C to 28°C, and 16 krad turned out to be optimum dosage for sprout prevention of potato tubers under this experimental condition.

A previous report[19] is available on sprout inhibiting effects of irradiation on several Korean varieties. However, the report is not comparable to the present result, since no quantitative data on sprout growth were presented and dosage was entirely confounded with dose rate. Representative samples taken from potato tubers treated with various dosages of gamma ray are shown in Fig. 2. It is seen that the type and amount of sprout growth were very distinctly different due to dosage. Untreated tubers produced profuse apical sprouts. However, it was noticed that 2 krad treated potato tubers produced considerable amount of lateral sprouts. Many of the sprouts on potatoes treated with 4 or 8 krad were somewhat rosetted. It is interesting that typical rosette sprouts[20] were produced on some tubers. Although 8 krad gave almost practical control, sprout growth was completely inhibited on potato tubers treated with 16 krad. While untreated and 2 krad treated tubers exhibited very serious shrivelling, tubers treated with 16 krad kept firm through storage period.

As expected from sprouting pattern, increased dosage of gamma ray gradually reduced weight loss of potato tubers (Fig. 3). The percentage weight losses of untreated tubers exceeded 30% at the end of 2 month storage. However, 8 krad treatment resulted in about half of weight loss compared with control, and 16 krad treatment about one third. Along with reduced weight loss, durometer reading indicated that tuber firmness

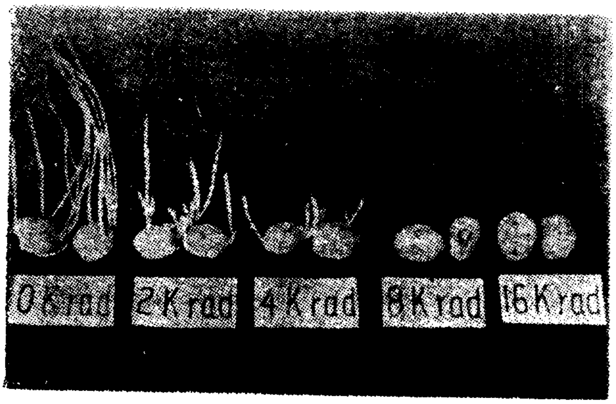

Fig. 2. Tubers stored at room temperature for 2 months after treatment with various dosages of gamma ray

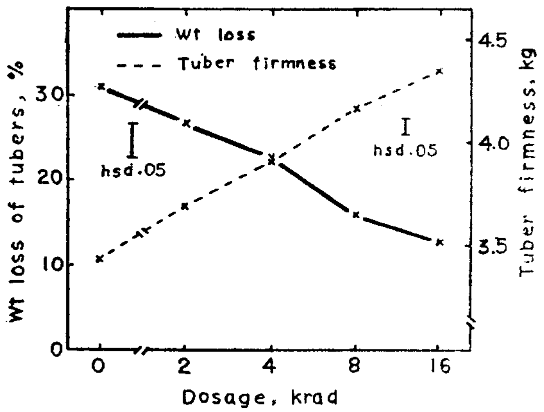

Fig. 3. Effects of various dosages of gamma ray on weight loss and firmness of potato tubers stored at room temperature. Brackets indicate honestly significant difference at 5% level by Tukey' procedure

was increased as dosage of gamma ray became higher (Fig. 3).

According to Table 1, there are no great differences in cooking quality of potato tubers treated with various dosages of gamma ray. Color observations indicated no blackspot, after cooking darkening and greening from any of irradiated tubers. In texture, tubers treated with 16 krad tended to be somewhat mealier than those of other treatments, although there was no statistical difference between dosages. No off-flavor or irradiation odor was recognized from irradiated tubers, and 16 krad treatment tended to give little higher flavor scores than other dosages. However, this score was not statistically significant from other scores.

Early workers[1] indicated that irradiated potatoes, regardless of dosages, were definitely preferred to untreated ones by the end of 8 month storage at 5～7°C, while no difference was noticed in taste up to 4 months of storage. Such preferable cooking quality of irradiated tubers in prolonged storage might be a natural consequence of sprout inhibiting effect. It is probable that the effect of irradiation on cooking quality would be rather indirect. Since the tuber to tuber variations are more important than irradiation effects in cooking quality test,[5] great numbers of samples will be necessary for valid results in organoleptic test. In the present study, examination of limited numbers of samples showed no recognizable difference in cooking quality, and caused no side effects such as black spot [6,21] or after cooking darkening.[6,21]

Table 1. Effects of various dosages of gamma ray on cooking quality of potato tubers stored at room temperature[x]

Dosage	Organoleptic scores[y]		
(krad)	Color	Texture	Flavor
0	2.9 a	3.4 a	2.8 a
2	2.9 a	3.8 a	3.1 a
4	3.0 a	3.4 a	3.0 a
8	2.9 a	3.8 a	3.1 a
16	3.1 a	3.9 a	3.5 a

x : Any two means followed by a common letter are not significantly different at 5% level by the honestly significant difference (hsd) of Tukey's procedure.

y : Rated using a scale of 1-5, where 5=excellent; 4=good; 3=fair; 2=poor; 1=unusable.

As a result of examining proximate composition of unpeeled potato tubers, it was shown that moisture content was gradually increased with increasing dosages of gamma ray. Tubers treated with 8 and 16 krad contained about 70% of moisture, and there was no great difference in moisture content between these two dosages and 4 krad. Tubers treated with 2 krad showed about 15% of reduction compared with ones treated with 4 krad, although there was no statistical difference between two dosages. Control and 2 krad treated tubers showed around 20% lower amount of moisture than 8 and 16 krad. Reduced content of moisture in 0 and 2 krad treated tubers might be attributed to high rate of transpiration of growing sprouts at room temperature. Tubers whose sprouts were completely inhibited showed somewhat lower amount of moisture content than freshly harvested tubers, possibly because of transpiration by tuber.

Most of previous work concerning the effect of ionizing radiation on carbohydrate content of potato tubers was conducted associating with potato chip quality. A number of investigators found that sugar content was higher in irradiated tubers than in untreated ones under varying condition.[1,2,7,13] However, it appears that irradiation has practically no effect on starch content,[5,13] except one case that control potatoes showed higher mean starch values than irradiated ones at the end of 4½ months of storage at 20°C, as shown by Parks et al.[5] In the present study, potatoes with no sprout growth tended to contain higher percentage of total carbohydrate, even though no statistical difference was found among various dosages of gamma ray treatments.

Contents of protein, fat, ash and fiber were not significantly different due to dosages. As figured out in Table 2, the sum of percentages of proximate composition in each dosage comprises respectively 68.1, 72.3, 88.8, 94.4 and 93.7%. Since all analytical values were expressed as quantities per 100 gram of original fresh weight, the value obtained by subtracting the sum of percentages from 100, shows a similar pattern as weight loss of potato tubers treated with various dosages of gamma ray.

Table 3 reveals that mineral contents of calcium, phosphorus and iron showed no difference among dosages, although 16 krad treated tubers tended to contain somewhat higher percentage. Schwimmer et al.[14] observed that an increase of inorganic phosphate of tubers irradiated with 5.2 krad occurred at a postirradiation temperature of 4.4°C during 16 days. However, no further information is available concerning the effect of irradiation on mineral contents as nutrition.

Table 3. Effects of various dosages of gamma ray on mineral contents of potato tubers stored at room temperature[x,y]

Dosage (krad)	Calcium (mg %)	Phosphorus (mg %)	Iron (mg %)
0	13.8 a	48.0 a	1.3 a
2	16.5 a	56.2 a	1.2 a
4	15.6 a	53.6 a	1.5 a
8	14.8 a	55.3 a	1.2 a
16	16.0 a	59.1 a	1.8 a

[x]: Data are expressed as gram per 100 gram of original fresh weight.
[y]: See footnote x, Table 1.

In vitamin assay, thiamine and riboflavin contents were considerably lower than reported values of potato tubers. Furthermore fluctuation was quite serious in thiamine content and there does not seem to be any logical explanation for this result. Riboflavin assay shows that tubers treated with higher dosages tend to contain higher percentage; however, this result is not completely valid since determination was not replicated. Tubers treated with various dosages of gamma ray showed no difference in niacin content. However, ascorbic acid content was distinctly higher in 8 and 16 krad treatments than in 0 and 2 krad treatments.

Table 2. Effects of various dosages of gamma ray on proximate composition of potato tubers stored at room temperature[x,y]

Dosage (krad)	Moisture(%)	Carbohydrate (%)	Protein(%)	Fat(%)	Ash(%)	Fiber(%)
0	48.5 a	14.5 a	2.3 a	0.4 a	0.7 a	1.7 a
2	53.3 ab	13.5 a	2.5 a	0.3 a	0.8 a	1.9 a
4	67.7 bc	14.8 a	3.2 a	0.4 a	0.6 a	2.1 a
8	71.0 c	15.8 a	4.1 a	0.4 a	0.9 a	2.2 a
16	69.9 c	17.3 a	2.7 a	0.4 a	0.8 a	2.6 a

[x]: Data are expressed as gram per 100 gram of original fresh weight.
[y]: See footnote x, Table 1.

Table 4. Effects of various dosages of gamma ray on vitamin contents of potato tubers stored at room temperature[x,y]

Dosage(krad)	Thiamine(μg %)	Riboflavin[z] (μg %)	Niacin (mg %)	Ascorbic acid(mg %)
0	15.7 ab	3.4	0.8 a	9.9 a
2	12.9 c	3.0	1.0 a	9.6 a
4	17.3 a	6.3	0.9 a	11.5 ab
8	16.3 a	8.6	0.7 a	13.1 b
16	14.0 bc	5.3	0.5 a	12.1 b

x: Data are expressed as gram per 100 gram of original fresh weight.
y: See footnote x, Table 1.
z: Not replicated.

Tubers treated with 4 krad contained essentially the same amount of ascorbic acid as 0 or 2 krad, and as 8 or 16 krad treated tubers. Since the potato is considered to be a good source of ascorbic acid, it is noticeable that irradiated tubers showed significantly higher percentage of ascorbic acid than extremely sprouted tubers. Previous workers[22] also reported that ascorbic acid levels of the irradiated tubers were higher than those of untreated tubers. According to Parks et al.,[5] various dosages of gamma ray did not result in consistent or large variation in the ascorbic acid content of potatoes. Their study showed that loss of ascorbic acid was mainly caused by storage temperature. Loss was more serious at 4°C than at 20°C storage temperature. However, Sereno et al.[13] and Lewis and Mathur[4] discovered that ascorbic acid was decreased almost immediately after irradiation, but partially restored in an extended storage. On the contrary, Schwimmer et al.[14] noticed that the ascorbic acid content was increased immediately after irradiation but decreased to control levels within 1 day. There was no evidence that dosage employed in this experiment destroyed any kind of vitamin. It is also possible that certain vitamin might have been destroyed, but partially restored during storage.

요 약

방사선 조사가 감자 塊莖의 萌芽抑制 및 영양가에 미치는 효과를 규명하기 위해서 0 krad로부터 16 krad 사이의 線量을 Irish Cobbler 品種에 처리하였다. 싹 생장량은 선량이 높아짐에 따라 감소되었고 16 krad 처리구에서 완전히 억제되었다. 이 최적선량에서 塊莖의 중량 손실은 현저히 감소했고 全저장 기간을 통해 硬度는 양호했다.

방사선 조사는 감자 塊莖의 cooking quality에 아무런 惡영향도 미치지 않았다. 저장 후에 塊莖내의 수분함량은 싹 생장량과 逆比例하였다. 본 실험에서 16 krad 처리구는 탄수화물 함량이 低線量처리구보다 다소 높은 경향을 보였고, ascorbic acid는 8 및 16 krad가 무처리구 및 2 krad보다 다량 함유되고 있음이 나타났다.

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