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ORIGINAL ARTICLE

Impact of post-harvest radiation treatment timing on shelf life and quality characteristics of potatoes

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Abstract The effects of gamma radiation treatment (50 and 100 Gy) on potato tubers irradiated at different days (10th, 30th and 50th) after harvest were studied during 5 months of storage at 10°C using Agria and Marfona varieties. A factorial experiment was done, based on a Randomized Complete Block Design with four replications. The 100 Gy radiation treatments on 10th and 30th days after harvest completely prevented sprouting at both varieties studied but on 50th day only Agria tubers not sprouted. This study indicated that early irradiation and absorbed radiation doses significantly decreased sprouting, percent weight loss and specific gravity of tubers. Reducing sugar content significantly increased by delay in irradiation and lower dose of radiation while non-reducing sugars did not decrease significantly by delay in irradiation and higher dose of radiation. The least increase in reducing sugars (10.2%) and most decrease in non-reducing sugar (−12.75%) were observed in tubers that irradiated on 10th day after harvest. The content of ascorbic acid was decreased by irradiation with higher dose. Although delay in irradiation caused less loss of ascorbic acid (8.5%) but showed greater metabolic changes as sprouting, weight loss, firmness, and sugars contents. Also, more increased delay in irradiation needed higher radiation doses for sprout inhibition.

Keywords Storage · Potato · γ-radiation · Different dates · Sprouting

Introduction

The existing methods for long term storage of potato are not adequate to control the deterioration as approximately 50% of the product is lost in few months of storage. Sprouting, weight loss and rotting are the major problems during storage. Extension of storage life and a reduction in post storage loss by radiation treatment would help to ensure a steadier supply and stabilize the prices, Brynjolfsson (1989).

Various methods are used to prolong shelf life of potatoes involved classical low-temperature storage and the use of sprouting inhibiting chemicals such as malic hydroxide, α–naphthalene acetic acid, methylester, isopropyl N-(3chlorophenyl)carbonate and 1, 2, 4, 5 tetra chloro-3nitro benzene. Treatment with such chemicals, however produce many undesirable side effects, Macqueen (1965). In fact the use of mechanical refrigeration for low–temperature storage is limited by economics and increasing the risk of freezing or chilling injury, Chourasia and Goswami (2001) and the use of chemical sprout inhibitors by food safety regulation. On the other hand, Ogava and Hayodo (1989) reported that low-temperature storages cause sweetening in potatoes. Such potatoes having high reducing and total sugars, were found to be unsuitable for processing (chips-making), Olsson et al. (2004), Kumar et al. (2007) and Ezekiel et al. (2007). Application of Gamma radiation treatment is a well-known method to reduce the spoilage without having any adverse effects on nutritional and sensory quality of foods. Its use is gradually increasing worldwide, WHO (1999). However, irradiation induced

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softening and some physical damage was reported for number of fruits and vegetables by many researches, Prakash et al. (2002), Rastogi and Raghavarao (2004) and Rastogi (2005). Also Joshi et al. (1990) showed that irradiated potatoes stored at 15°C for 6 months had lower sugar levels than control tubers stored at 2–4°C. So the use of radiation may be an alternative treatment for controlling undesirable changes in potatoes during long-term storage.

The appropriate use of radiation can extend shelf life, reduces the requirement of chemicals for preservation and pest control, produces sterilized products that can be stored without refrigeration, delays the ripening of fruits and vegetables and limits the deterioration of quality of stored tuber and bulb crops by preventing postharvest sprouting, Wierbicki (1986), Wang and Chao (2003). The critical problem, however, is to find the optimum radiation level that can fulfill the preservation requirements without causing serious chemical alteration of the food, which would affect its organic acceptability and wholesomeness, Farkas (1985). As Frazier et al. (2006) showed successful sprout suppression was achieved with doses of 40–50 Gy while higher doses caused undesirable increase in reducing sugars in the tubers. On the other hand Umeda et al (1969) showed that higher storage temperature required higher dose of radiation. From developmental studies conducted in many countries, doses between 50 and 150 Gy preferable a dose range from 60 to 120 Gy are recommended for sprout control of tubers and in dormant state shortly after harvest, IAEA (1982). Many studies have indicated that irradiation during the dormancy period of tubers is the most effective for sprout control, Thomas (1984). The length of the dormancy period of potatoes is affected little by storage temperature, but it is significantly dependent upon their variety. Agria and Marfona varieties have a dormancy period of about 60 and 45 days after harvest, respectively, Afshari (2006). The results of many of these studies are not comparable because of the differences in materials used and storage conditions, Golachowski (1985).

The objectives of this study were to determine interaction of variety, timing of irradiation treatment and radiation dose on sprouting and on physical and nutritional changes of potato tubers.

Material and methods

Potato tubers of Agria and Marfona varieties were planted on April 15, 2008 and fertilized with 220 kg/ha in 16-16-16 NPK mixed fertilizer at the Damavand area. Samples were harvested on mid October 2008 washed, dried and graded based upon weight (170–230 g) tubers and brought to the Nuclear Research Center in Karaj on the same day. Manageable quantities of approximately 3 kg of each sample were placed in aerated polyethylene mesh bags and placed at 10°C with 95% relative humidity for 10 days. Samples were irradiated on 10th, 30th and 50th days after harvest with 50 and 100 Gy. The dose rate (the mean of maximum and minimum dose rates) at the time of irradiation was 21.83 Gy/min. Each sample was placed in an iron basket and was exposed to irradiation (cobalt-60) for different periods of time. The periods of irradiation were 2 min and 18 s, and 4 min 36 s for 50 Gy and 100 Gy, respectively. After irradiation tubers were stored at 10°C with 85 to 90% relative humidity.

The experiment was designed as factorial (Two varieties × Two radiation doses × Three days of irradiation after harvest) based on a Randomized Complete Block Design (RCBD) with four replications (four samples for each treatment). A total of 12 treatments were used in each replicate. Analysis of variance and statistics were done using SAS.

Sprout weight and weight loss

Sample were removed from storage room at the termination of the storage period and the sprouts from the sprouted tubers were removed, weighed and expressed in gr/3 kg of tubers. Final tuber weight (tuber weight after storage minus sprout) was subtracted from the initial weight prior to storage then the weight loss was determined.

Specific gravity

The following formula was used for determining the specific gravity, (Freeman et al. 1998)

$$\text{Specific gravity} = \frac{\text{Weight in air}}{(\text{Weight in air} - \text{weight in water})}$$

A hanging tuber was weight in water to determine the weight in water. The mean of five measurements for each observation expressed as specific gravity. Specific gravity was determined prior to irradiation and after irradiation and storage. Differences were converted into percentages of original specific gravity.

Measurement of firmness

Firmness was measured as Kg with 0.79 Cm probe of Ft327 brand penetrometer (Effegi, Alfonsine, Italy). Measurements were performed as a single reading in the middle part of the tuber. The mean of five measurements was reported.

Sugar analysis

Total soluble carbohydrates and reducing sugars (glucose and fructose) were determined before irradiation and immediately after the termination of storage period. The procedure was that outlined by Revathy et al. (2007). Six lengthwise wedge pieces from the tubers were blended for 30 s in a warning blender to which a few grains of sodium bisulfate (NaHSO3) were added to prevent browning. The mixture was stirred and to a 20 g of 40 g sample was added 50 ml of 50% ethanol in a beaker, and allowed to settle on shredded ice until ready to use. Soluble reducing sugars were determined by the dinitro-phenol colormetric method. Intensity of color was read at 600 nm on a Bausch and Lomb Spectrophotometer (Spectronic 21, USA). Standards containing 0–0.4 mg/ml dextrose were used with the samples. The remaining 20 g of sample were placed in an oven at 70°C for 48 h to determine percent dry matter. Total sugar was determined by hydrolysis of a 10 ul aliquot with concentrate sulfuric acid and 5% phenol. Intensity of color was read at 485 nm on a spectrophotometer. Standards containing 0–40 ug/ml dextrose were used for the assay. Difference between total sugar (%) and reducing sugars(%) was considered non-reducing sugar percent (sucrose). All sugar contents were expressed on a dry weight basis and the differences between preirradiation and postirradiation storage were calculated on a percentage basis of preirradiation weight.

Ascorbic acid determination

Method of enzymatic analysis was used for the estimation of ascorbic acid content, Beutler and Beinstingl (1980). The ascorbic acid enzymatic analysis kit was obtained from Boehringer Mannheim Biochemicals (product #409677) Indianapolis, Indiana and the procedure was followed as per instruction manual (Instructions for the analysis of food stuffs, methods of enzymatic analysis). One gram of lyophilized potato tuber tissue ground to 40 meshs was extracted in 40 ml of double distilled water in a 50 ml volumetric flask to which was added 5 ml of metaphosphoric acid (15% w/v) and 0.1 ml of n-octanol and thoroughly mixed. The PH was adjusted to 3.4–4 with potassium hydroxide (2 mol/1) using PH meter (model 701/ Digital Ionalyzer). The final volume was brought to 50 ml with redistilled water and filtrated through a wattman No.1 filter paper. The filtrate was used for analysis according to the procedure outlined in the instruction manual. Optical density readings at 578 nm were recorded in triplicate for each sample on a spectrophotometer (Bausch and Lomb spectronic 21) and total ascorbic acid content (ascorbic acid + dehydroascorbic acid) was determined. The difference in ascorbic acid was calculated and expressed on percentage basis of prestorage content.

Results and discussion

Tuber quality

The nutritional composition of tubers after harvest prior to storage is given in Table 1. Regarding to quality of tubers after harvest, the changes in nutritional composition of potato tubers were analyzed. Reducing sugars and specific gravity increased while Non-reducing sugars and ascorbic acid decreased with five months storage at 10°C.

Sprout weigh

Increasing radiation dose significantly ($p<0.01$) reduced sprouting. Radiation dose of 100 Gy on 10th and 30th days after harvest completely prevented sprouting at both varieties studied but on 50th day only Agria tubers not sprouted may be due to shorter dormancy period of Marfona variety. Among tubers that Irradiated with 50 Gy, Agria tubers irradiated on 10th day after harvest had the least sprouting (0.69 gr/3 kg tuber) which indicated the optimum dose for this variety in this date is a little more than 50 Gy but the optimum dose for Marfona variety is a little less than 100 Gy. The 50 Gy dose partially inhibited sprouting in tubers that irradiated on 50th and 20th days after harvest however a gradual increase in sprout weight was observed with the increase delay in irradiation (Fig. 1).

To pay attention to interaction between variety and radiation date, Agria tubers had less sprouting than Marfona tubers with irradiation on 10th day after harvest and had more sprouting than Marfona tubers with irradiation on the other dates. Higher dose radiation with less increased delay after harvest significantly ($p<0.01$) reduced sprouting which showed that irradiation immediately after harvest had the least sprout growth. Regarding to interaction between all three factors i.e. variety, day of irradiation and radiation dose, irradiation day after irradiation reduced the effect of sprout inhibition, indicating that more increased delay in irradiation needed higher radiation doses. More increased delay in irradiation caused a significant increase ($p<0.01$) in degree of sprouting since irradiation on 30th and 50th days after harvest result in some potatoes coming out of dormancy period. There was minimum sprout development (1.7 gr/ 3 kg tuber) in tubers irradiated on 10th day after harvest. Tubers immediately after harvest are in an active metabolic state and are more sensitive to irradiation, IAEA (1982) which disrupted nucleic acid, nucleotide and hormonal synthesizing system, Josephson and Peterson (1983) and therefore failed to sprout.

The 50 Gy irradiated tubers that irradiated on 30th and 50th days after harvest were not suitable for fresh market being soft and shriveled due to sprouting. The sprout inhibition effect of irradiation may be the basis for physical and biochemical changes in tubers during storage.

Weight loss

In this study, variety, day of irradiation after harvest and absorbed radiation doses all significantly ($p<0.01$) affected

Table 1 Agria and Marfona Tuber quality after harvest prior to irradiation and storage (n=20)

Variety	Reducing sugars (%)	Non-reducing sugars(%)	Ascorbic acid mg/100 g	Specific gravity	Firmness Kg
Agria	0.89	1.53	71	1.083	7.87
Marfona	1.01	1.25	75	1.079	7.71

potato weight loss (Fig. 1). Less increased delay in irradiation after harvest and absorbed radiation doses significantly decreased weight loss. The weight loss of Agria (10.2%) and Marfona (9.5%) tubers were significantly (p<0.01) different. The averages of weight losses of both varieties irradiated at 10, 30 and 50 days after harvest were 7.6, 9.5 and 12.5%, respectively. The greater weight loss of later irradiation may be due to more sprout development (Fig. 1), higher respiration rate and increased membrane permeability, Chachin and Iwata (1981).

Irradiation at doses 50 and 100 Gy had weight loss 11.3 and 8.6%, respectively at both varieties. Weight loss decreased with increasing radiation doses as was found by Sparks and Iritani (1964) however Agria tubers that irradiated with dose 100 Gy on 10th day after harvest, completely inhibited sprouting tubers, lost more weight (7.5%) than dose 50 Gy (7.3%). This may be due to a delay in wound healing and a change in the membrane function of the irradiated tubers which increase in permeability causing higher respiration, Chachin and Iwata (1981).

The difference in loss due to absorbed radiation doses decreased with early irradiation which showed that delay in irradiation required higher doses of radiation. Therefore storage of tubers is possible with delay in irradiation if irradiated with higher doses.

The major factors contributing to weight loss of stored tubers are sprouting which caused 31.4% increase in weight loss, moisture loss, respiration and handling. The increase in membrane permeability, delay in periderm formation, change in specific gravity, organic acid contents and sugars and amino acids may also in part have contributed to the weight loss, Chachin and Iwata (1981).

Specific gravity and firmness

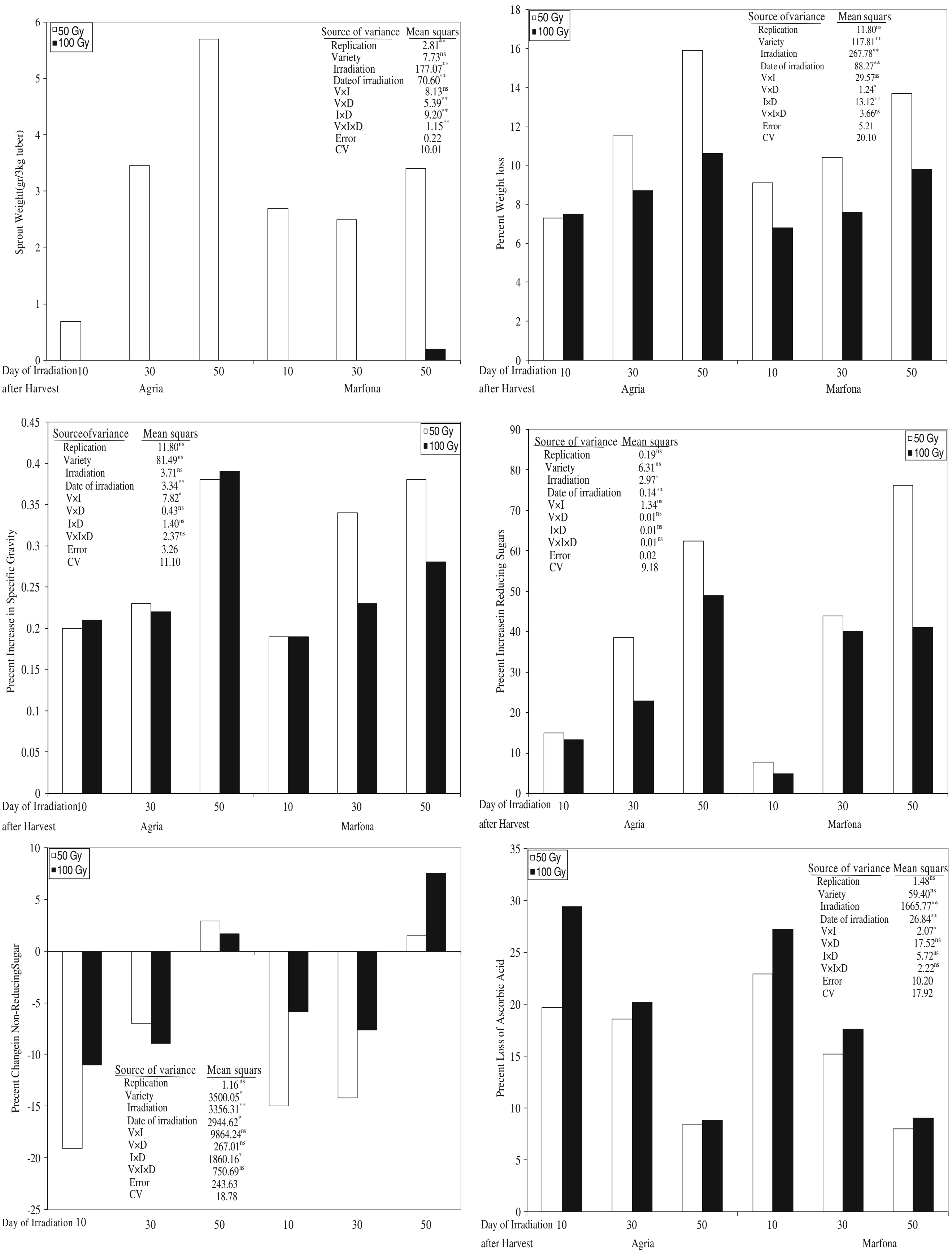
The change in specific gravity was significantly (p<0.01) less in tubers from earlier irradiation than the other tubers (Fig. 1). Agria and Marfona tubers irradiated on 50th day after harvest showed greatest change (0.36% increase) in specific gravity followed by the tubers irradiated on 30th day after harvest. More sprouting and weight loss of the tubers irradiated late could be a reason for greater changes in specific gravity. Regarding the interaction between variety and radiation dose, the difference between 50 and 100 Gy on change in specific gravity of Agria tubers was not significant while the specific gravities of Marfona tubers irradiated with 50 Gy and 100 Gy doses increased 0.30% and 0.23%, respectively. The increase in specific gravity of non-sprouting tubers (100 Gy radiation) maybe due to delay periderm setting which could cause higher respiration and moisture loss, Chachin and Iwata (1981).

Although the specific gravity increased, the loss of firmness became clearer in all tubers of two varieties during the storage at 10°C with 85 to 90% relative humidity. None of three factors and their interactions had any effect on loss of firmness. The percentage losses of firmness in Agria and Marfona were determined to be 29 and 20% under these conditions at the end of 5 months storage. However, the loss of firmness was reduced to 8 and 6% in tubers of Agria and Marfona, respectively with irradiation on 10th day after harvest. In this study, there was overall increase in the specific gravity of tubers after 5 months storage. The increase of Specific gravity may be due to sprouting, moisture loss and respiration.

Sugars metabolism

Results of sugar metabolism are given in Fig. 1. Day of irradiation after harvest and absorbed radiation dose significantly reduced reducing sugars. Tubers irradiated on 50th day after harvest accumulated significantly (p<0.01) more reducing sugars (57.1% increase), which were lower (10.2% increase) in tubers that irradiated on 10th day after harvest indicating the effects of physiological aging so the later the date of irradiation, the greater the increase in reducing sugars. Irradiated tubers with 100 Gy had lower increase in reducing sugars content(28.5% increase) as compared to 50 Gy irradiated tubers(40.6% increase) Jaarma (1966), Thomas (1984), Fiszer et al. (1985). This may be due to utilization of reducing sugars as substrate for respiration because these tubers sprouted and hence may have utilized the excess sugars for energy production during sprouting and for higher respiration rate. These findings agree to those reported by Thomas (1984).

Variety, day of irradiation after harvest and radiation significantly affected the changes in non-reducing sugar. Tubers irradiated on 50th day after harvest behaved differently in response to irradiation than tubers irradiated on 10th and 30th days after harvest. Maximum of non-reducing sugar (3.4% increase) was found in tubers



Source of variance	Mean squars
Replication	2.81**
Variety	7.73^{ns}
Irradiation	177.07**
Dateof irradiation	70.60**
V×I	8.13^{ns}
V×D	5.39**
I×D	9.20**
V×I×D	1.15**
Error	0.22
CV	10.01

Source ofvariance	Mean squars
Replication	11.80^{ns}
Variety	117.81**
Irradiation	267.78**
Date of irradiation	88.27**
V×I	29.57^{ns}
V×D	1.24*
I×D	13.12**
V×I×D	3.66^{ns}
Error	5.21
CV	20.10

Sourceofvariance	Mean squars
Replication	11.80^{ns}
Variety	81.49^{ns}
Irradiation	3.71^{ns}
Date of irradiation	3.34**
V×I	7.82*
V×D	0.43^{ns}
I×D	1.40^{ns}
V×I×D	2.37^{ns}
Error	3.26
CV	11.10

Source of variance	Mean squars
Replication	0.19^{ns}
Variety	6.31^{ns}
Irradiation	2.97*
Date of irradiation	0.14**
V×I	1.34^{ns}
V×D	0.01^{ns}
I×D	0.01^{ns}
V×I×D	0.01^{ns}
Error	0.02
CV	9.18

Source of variance	Mean squars
Replication	1.16^{ns}
Variety	3500.05*
Irradiation	3356.31**
Date of irradiation	2944.62*
V×I	9864.24^{ns}
V×D	267.01^{ns}
I×D	1860.16*
V×I×D	750.69^{ns}
Error	243.63
CV	18.78

Source of variance	Mean squars
Replication	1.48^{ns}
Variety	59.40^{ns}
Irradiation	1665.77**
Date of irradiation	26.84**
V×I	2.07*
V×D	17.52^{ns}
I×D	5.72^{ns}
V×I×D	2.22^{ns}
Error	10.20
CV	17.92

Fig. 1 Physioco-chemical changes in Agria and Marfona potato tubers irradiated with different dosages during storage at 10°C (*n*=20)

irradiated on 50th day after harvest. Higher dose of radiation (100 Gy) caused less decrease in non-reducing sugar (4%) as compared to 50 Gy radiation (caused 8.4% decrease). The increase in activity of enzymes (sucrose synthase, invertase and phosphorylase) may be an explanation for such sugars changes of potato tubers in response to irradiation. The increase in starch decomposition was suggested be due to increase of phosphorylase activity. Sucrose synthase catalyzes formation sucrose from fructose and glucose but invertase catalyzes the cleavage of sucrose to form fructose and glucose. Invertase activity in irradiated tubers stored for 1 year was about 50% of activity from the corresponding control tubers, Jaarma, (1966) while irradiation may have increased activity of sucrose synthase as irradiation induces an active metabolic state for shorter period of time, Ussaf and Nair (1981). Therefore, increase in radiation dose did not increase reducing sugars and did not decrease non-reducing sugars significantly. Irradiation with less delay after harvest significantly ($p<0.05$) decreased non-reducing sugars. An increase in reducing sugars (Fig. 1) and a general decrease in non-reducing sugars showed some relationship. These results are contrary to those of Hayashi and Asoka (1985) who applied very high radiation dosages such as 300–400 Gy to potato tubers and stored those tubers for shorter period of time, which may have activated sucrose synthesis through increase in enzymes and reduced the synthesis of reducing sugars. Agria tubers significantly had more decrease in non-reducing sugars and had less increase of reducing sugars as compared to Marfona tubers. The decreased levels of sugars in irradiated tubers are important for a good color in fried potato products, Biedermann-Brem et al. (2003). Reconditioning of stored potatoes limitedly can decrease reducing sugars and improvement in chip colour, Kumer and Ezekiel (2005).

Ascorbic acid metabolism

Percents of ascorbic acid loss in irradiated potatoes are presented in Fig. 1. Tubers that irradiated on 50th day after harvest which were sprouted and physiologically older lost 8.5% of ascorbic acid during storage. Maximum loss (24.8%) was observed in tubers that irradiated on 10th day after harvest. These results indicted that decrease in effectiveness of sprout inhibition by delayed irradiation of potato tubers may result from the increase in ascorbic acid and reducing sugar which are in the inner buds at the time of emergence from the dormancy state. Absorbed radiation dose generally tended to decrease ascorbic acid loss (15.4%) at lower dose level (50 Gy) in all tubers. The loss increased (18.7%) at higher dose such as 100 Gy in tubers from all three days of irradiation after harvest. These results agree with the findings of Shirsat and Thomas (1998) and Wang and Chao (2003).

Irradiation on 50th day after harvest on tubers resulted in comparable losses at both 50 and 100 Gy doses (Fig. 1). This indicates delay in irradiation requires higher doses of radiation for the extension of shelf life of potato tubers. Interaction of variety and radiation dose was significant ($p<0.05$). The ascorbic acid loss of Agria (15.5%) and Marfona (15.4%) tubers were not different significantly in response to 50 Gy radiation while 100 Gy radiation caused greater ascorbic acid loss in Agria tuber as compared to Marfona tubers. The tubers irradiated with less delay after harvest were subject to greater loss of ascorbic acid in response to higher doses of radiation. Potato tubers in active metabolic state after harvest seem to be more sensitive to irradiation as indicated IAEA (1982) that living organisms suffer more radiation injury. There is usually a decrease of ascorbic acid content in potato tubers during storage as reported in the findings of Ogata and Tatsumi (1973) and Nouri and Toofanian (2001).

Conclusion

In this study, the effects of gamma radiation treatment prior to prolonged storage were investigated on Agria and Marfona tubers components. Tubers that irradiated immediately after harvest had no sprouting at 100 Gy dose and least sprouting at 50 Gy dose while irradiation on 50th day after harvest caused some sprouting even when irradiated at 100 Gy dose. The optimum dose to sprout inhibition for Agria variety is a little more than 50 Gy but the optimum dose for Marfona variety is a little less than 100 Gy treatment on 10 day after harvest. Irradiated tubers with 50 Gy sprouted extensively and were not suitable for any use. The sprout inhibition effect of irradiation may be the basis for physical and biochemical changes in tubers during storage. Even though delay in irradiation caused low ascorbic acid loss but increased the detrimental changes so delay in irradiation is not recommended. Reducing sugar content significantly increased by delay in irradiation and lower dose of radiation while non-reducing sugar did not decrease significantly by delay in irradiation and higher dose of radiation. The least increase of reducing sugars and most decrease of non-reducing sugar were observed in tubers that irradiated immediately after harvest. Irradiation in general tended to increase the loss of ascorbic acid with dose increase, which was greater with early irradiation. The application of 50 and 100 Gy of ionizing radiation to potato tubers did not bring noticeable improvement to maintain firmness, but irradiation at 100 Gy immediately after harvest was found to be effective postharvest treatment for sprout suppression during long term storage at elevated temperature (10°C).

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