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Effect of gamma irradiation on potato (*Solanum tuberosum* L.) tubers influencing post-harvest quality parameters

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ABSTRACT

In this study potato tubers (Solanum tuberosum L. var Kufri Jyoti) were exposed to radiation dosages of 150 gray (Gy) and 500 gray (Gy) to study the post-harvest quality parameters of this horticultural crop. The treated tubers were stored at two different temperatures (6^0 C and 15^0 C) along with storage under ambient condition. The changes in the various physical quality parameters as well as biochemical changes were determined two months after storage. From this study, it was found that radiation may act as an effective tool for sprouting inhibition. 500 gray (Gy) radiation was found to be detrimental for the tubers as discolouration of the tubers kept under ambient condition was observed within two weeks of the treatment. Considerable weight loss, significant loss in firmness, change in specific gravity and loss of ascorbic acid along with rapid discoloration was observed. The tubers exposed to radiation and subsequently stored under a lower temperature range (6^0 C) showed improved physical quality aspects compared to the tubers stored at an elevated temperature (15^0 C) or ambient conditions but resulted in higher sugar accumulation due to 'cold induced sweetening' phenomena. Thus storage at 15^O C may be recommended for retaining the physical quality.

Keywords : Cold induced sweetening, discolouration, irradiation, post harvest quality, sprouting

Potato (*Solanum tuberosum* L.) has emerged as fourth most important crop in India. A short duration crop of great food value maturing in a relatively shorter duration of time compared to cereals like rice and wheat, potato constitutes an important part in Indian vegetable basket. Poor handling and storage, under tropical and sub-tropical conditions accounts for sprouting, rotting and low temperature sweetening, the major reason of post-harvest loss. Extension of storage life after treating with radiation ensures a steady supply and price stabilization throughout the year (Brynjolfsson, 1989). Factors contributing to qualitative and quantitative deterioration of potatoes can be grouped into four categories comprising physical, physiological, microbiological and entomological factors.

Dormancy is a physical state in which tubers do not sprout even when placed under conditions ideal for sprout growth *i.e.* the optimum temperature being in the range of 18 to 20º C and relative humidity around 90 per cent and stored in complete darkness. Indian potato cultivars can be divided into three categories as short dormancy (< 6weeks, e.g. *Kufri Bahar*); medium dormancy (6-8 weeks e.g.-*Kufri Jyoti*) and long dormancy (> 8 weeks, e.g. *Kufri Gindhumi*) Soil and environmental conditions during crop growth have strong influence of the dormancy period. Cold environment with high humidity increases the dormancy period while dry conditions and warm weather reduces the dormancy period. Lower concentration oxygen (O_2) and higher concentration of carbon-di-oxide (CO_2) hasten the process of dormancy stimulating sprout growth.

Sprout growth begins at the end of dormancy period. Once sprouted, potatoes start losing weight, their appearance is affected by shriveling and they lose marketability both for table as well as processing purpose. Temperature has strong influence on sprout growth. Generally potatoes do not sprout when the storage temperature is less than 4º C. Applications of several chemicals to inhibit sprouting is common. Naphthalene acetic acid (NAA) and its derivative methyl ester of alpha naphthalene acetic acid (MENA) have been reported to considerably suppress sprouting. Chlorpropham CIPC (Isopropyl carbamate) is the most commonly used chemical to inhibit sprouting and at present is only chemical registered for commercial application in India.

Potatoes contain both simple (mono and di sachharides) and complex (starch) carbohydrates. Of the total carbohydrate content, about 88 per cent is present in the form of starch in potatoes. A higher concentration of reducing sugars and total sugars of high molecular weight render potatoes unsuitable for processing.

The objective of the study was to study the optimum irradiation dosage and storage temperature that would help to prolong the shelf life of the tuber by adequately suppressing the sprout without a decrease in tuber quality.

MATERIALS AND METHODS

Potato (*Solanum tuberosum* L.) variety *Kufri Jyoti* was cultivated at Haringhata, Nadia, West Bengal (22.9605^{0}N, 88.5674^{0}E), during the period of October

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2016 to March 2017. Seed tubers weighing 50-100 g were planted on 24th October, 2016. Ridge and furrow method was adopted and tubers were planted at a spacing of 60 × 20 cm. Fertilizers were applied at the rate of 180 kg nitrogen (N), 80 kg phosphorus (P_2O_5) and 100 kg potassium (K_2O) per hectare (ha). Irrigation was applied before planting as it is advantageous for uniform germination. The second irrigation was given after a week after planting and subsequent irrigations were provided as and when required. Harvesting was carried out on 1st March, 2017. A total of 35 kg of potatoes were used for the purpose of this experimental study. The selected tubers were weighed and stored under normal ambient condition on 2nd March, 2017 in the Rice Based Agro Processing Centre of Bidhan Chandra Krishi Viswavidyalaya.

Application of gamma radiation

Gamma radiation was given to the samples in GAMMA CHAMBER 5000 at RNARC (Regional Nuclear Agricultural Research Centre), BCKV, Mohanpur, Nadia, West Bengal. Gamma radiation chamber 5000 was a compact self-shielded Cobalt 60 gamma irradiator providing an irradiation volume of approximately 5000 cc. Radiation is provided by a set of stationary Cobalt 60 source placed in a cylindrical cage. The sources are doubly encapsulated in corrosion resistant stainless steel pencils and are tested in accordance with international standards. The lead shield provided around the source is adequate to keep the external radiation field well within permissible limit. The specifications of GAMMA CHAMBER 5000 at RNARC are as follows: 1. Irradiation volume 5000 cc. 2. Size of sample chamber 17.2 cm (dia.) × 20.5cm (height) 3. Shielding material Lead and Stainless Steel. 4. Weight 5600 kg. 5. Size 125 ×106.5 ×150cm. 6. Timer range 6 sec onwards. The applied dose of radiation in this experimental study has been tabulated in table 1.

Table 1: Specifications of applied dose of radiation in this experimental study

Dose	150Gy	500Gy
Temperature	34.8^{0}C	36.9^{0}C
Radiation time	1 min 14sec	4min 08sec
Dosage rate	7.235 KGy hr^{-1}	7.235KGy hr^{-1}

Fifteen kilogram samples were irradiated at two specific dosage at 15th day of harvest (17th March, 2017). Half of the sample *i.e.* 7.5 kg was given a radiation dose of 150 gray (Gy) and rest 7.5 kg was given 500 gray (Gy) radiation. Subsequently out of the entire amount of samples exposed to 150 gray (Gy) radiation, 2.5 kg were kept at 6^0 C storage temperature, 2.5 kg were kept at 15^0 C storage temperature and rest 2.5 kg were stored under ambient temperature. A similar condition of storage temperatures were followed for 500 gray (Gy) irradiated samples. Again from the original collected stock, 15 kg of the samples were irradiated 30 days after harvest (2nd April, 2017). The procedure was repeated as before with 2.5 kg sample kept untreated under ambient condition as control.

A specific method of reference was adopted. The samples were named in accordance to the following sequence: P-days after harvest-radiation dose-storage temperature. As for example P-15-500-6 designates sample 15 days after harvest irradiated with 500 gray (Gy) dose and stored at 6^0 C storage temperature. For ambient storage we use 'A' in the place of storage temperature and for untreated sample kept under ambient we the symbol 'UA'.

Methodology for physical analysis

The following physical properties were studied after a storage period of two (02) months.

1. Sprout weight.
2. Weight loss.
3. Specific gravity.
4. Texture analysis.

Sprout weight

The sprouts from the sprouted tubers were cut gently with a sharp knife and weighed. The sprout weights were expressed as the percentage of total tuber weight without sprout.

Weight loss

Weight of potato tubers was recorded prior to radiation. Regular inspection was carried out during the study and the weight of the samples was recorded twice a week. Rotten tubers were sorted out and after recording of their weight were discarded. Final tuber weight (tuber weight after storage without spout) was subtracted from the initial weight prior to storage to determine weight loss. Percentage weight loss was estimated using formula- (Initial weight-final weight)/ (initial weight) ×100%

Specific gravity

Specific gravity is calculated as the ratio of the weight of the tuber to the weight of the same volume of water. The most accepted and probably the more accurate method is to actually weigh the sample in air and under water. Undamaged tubers free of soil and any hollow part was used. The tubers were weighed in air, transferred to another weighing basket (weight of the basket recorded) and weighed under water.

Texture analysis

Texture of potato is an elusive quality measured by firmness test and shearing test. In this study analysis of the firmness and shearing test was carried out in **TA.XT Plus Texture Analyser**.

Firmness test

In this study only peak force was measured during puncture test to correlate firmness of the tubers. The sample was placed on the platform of texture analyzer and a 2 cm diameter cylindrical probe was used, the probe was attached with an aluminum probe adaptor which was subsequently connected to the probe of the texture analyzer. The test was done on the central part of the potato tubers on each face. Specification of texture analyzer for firmness test. 1. Test mode Compression. 2. Pre-test speed 2mm/s. 3. Test speed 1 mm/s. 4. Post-test speed 10 mm/s. 5. Targret mode Distance. 6. Force 100.00 g 7. Distance 5.00 mm. 8. Strain 10%. 9. Trigger type Auto. 10. Trigger force 20 g. 11. Probe model no. P/2. 12. Probe type 2 cm diameter, 3.14 mm^2, stainless steel. 13. Points per second 200.

Shearing test

Shearing test was performed to determine the amount of force that was required to cut the tuber. HDP/BSK (Heavy Duty Platform/Blade Shearing Knife) was used as cutting instrument. In operation the blade was firmly held by means of a blade holder which was affixed above and descends into the slot of the Heavy Duty Platform (HDP) which both acts as a guide for the blade while providing support for the product. Specification of texture analyzer for shearing test. 1. Test mode Compression. 2. Pre-test speed 2.0 mm/s. 3. Test speed 2.0 mm/s. 4. Post-test speed 10 mm/s. 5. Targret mode Distance. 6. Distance 12.00 mm. 7. Strain 10%. 8. Trigger type Auto. 9. Trigger force 5 g. 10. Probe model no. HDP/BSK. 11. Probe type Blade set with knife 12. Points per second 200.

Analysis of biochemical parameters

Estimation of total soluble sugar (TSS)

Total soluble sugar was measured by anthrone reagent method (Hedge and Hofreiter, 1962). 0.5 g of the sample was taken for the analysis and the colour was recorded spectrophotometrically at 630 nm. Glucose was used as standard.

Estimation of starch

Starch was estimated by anthrone reagent method (Thayumanavan and Sadasivam, 1984). 0.5 g was used for the study. The change in colour was observed at 630 nm with glucose as standard. Starch content was calculated by multiplying the glucose content of the samples obtained from the standard curve of Glucose by a factor of 0.9.

Estimation of ascorbic acid

Ascorbic acid was determined by the 2,6-dichlorophenol indophenol (DCPIP) titration procedure as per method described by Casanas *et al.* (2002) with 1g of fresh tissue. The ascorbic acid content (mg/100g) was determined using the following formula:

Amount of ascorbic acid (mg/100g) = $(0.5\times20\times100\times V_2)/(1\times10\times V_1)$

V_1= DCPIP dye consumed by 0.5 mg ascorbic acid

V_2= DCPIP dye consumed by 10 ml of test solution.

RESULTS AND DISCUSSION

The food and drug administration (FDA) has approved irradiation as an effective technique for preservation and increasing storage life of meat, fresh fruits, vegetables and spice. This process is used in certain fruits and vegetables for delaying or inhibiting sprouting and ripening process (Ganguly *et al.*, 2012). The process of food irradiation is coined as cold pasteurization as this kind of treatment does not cause any significant rise in temperature. The results of this study in the light of the above statement for enhancing storage life of potatoes have been discussed below.

Sprout weight

The study reported no significant sprouting in case of the irradiated samples either radiated with 150 gray (Gy) or 500 gray (Gy) for both 6° C and 15° C storage temperature conditions and also for tubers kept at ambient temperature condition. Date of irradiation from harvest was also found to have no effect on the variation of sprouting for the samples which were exposed to radiation at a specific time interval of fifteen 15 and thirty 30 days after harvest respectively and was in accordance to that reported by Rezaee *et al.* (2013). Generally irradiation has positive effect in inhibiting sprouting; the mechanism involves disruption of nucleic acid, nucleotide and hormone synthesizing system. Sprouting was observed in case of untreated samples kept at ambient temperature; the weight as evaluated was 0.793 per cent. Thus it can be stated that radiation of 150 gray (Gy) dosage is sufficient to inhibit sprouting under the given conditions.

Weight loss

Potato tubers lose weight in the process of respiration and during conversion of sugars and starches to carbohydrate, carbon-di-oxide (CO_2) and water. Tubers may lose moisture because of vapour pressure difference

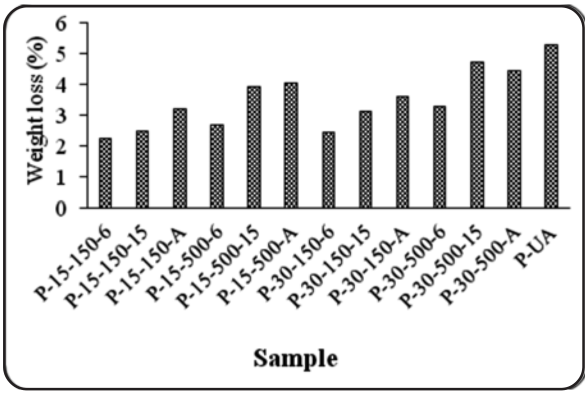

Fig. 1: Graph showing weight loss of the tubers

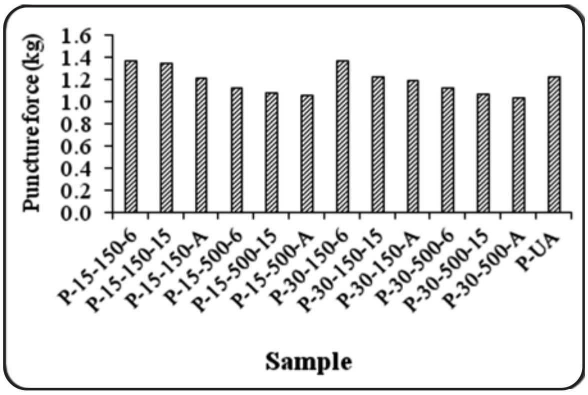

Fig. 2: Graph showing peak force in firmness test

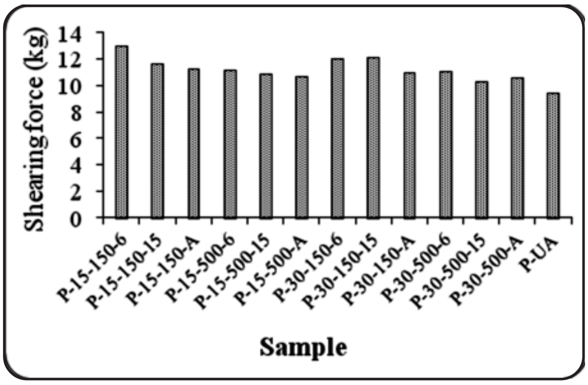

Fig. 3: peak force in of shearing

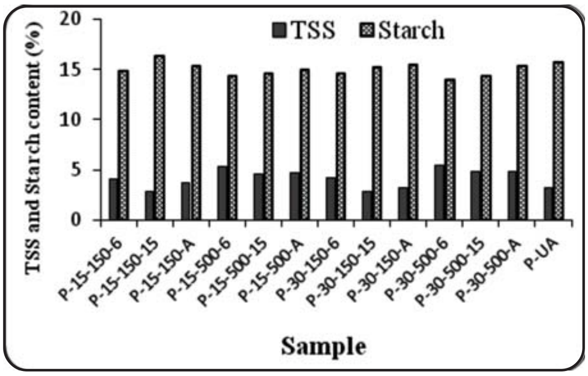

Fig. 4: TSS and starch content of the tubers

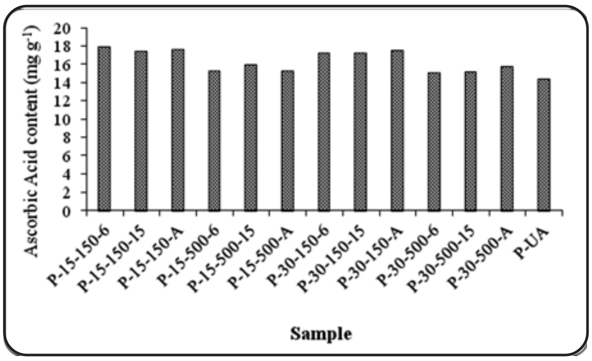

Fig. 5: Graph representing Ascorbic acid content of the tubers

between the tubers and surrounding air. The intensity of the dehydration and respiration processes were significantly lowered in irradiated potatoes in comparison with the controls (Fiszer *et al*., 1985).

Interestingly, in this study, the tubers exposed to a radiation of 500 gray (Gy) dose showed a significant tendency to rot (Frazier *et al*., 2006). This tendency to rot may be due to the delay in suberization, restricting the formation of a wound periderm, thus providing a condition for disease causing pathogens to act (Metlitsky *et al*., 1957).

Fig. 1 shows the variation of weight loss (%) of the samples after the storage period. Weight loss is maximum in case of untreated tubers, whereas weight loss in case of tubers treated with 150 gray (Gy) irradiation dosage has been found to be much lower. For a particular treatment, greater loss of weight occurs in irradiated potatoes kept at 15^0 C than those kept at 6^0 C. This occurrence may be due to higher respiration rate and increased membrane permeability in potatoes stored at 15^0C (Takano *et al*., 1974). Irradiation in combination with early date of irradiation showed a variation in weight loss. Weight loss in the sample, irradiated with 150 gray (Gy) after 15 days of harvest and kept at 15^0 C is 2.47 per cent, whereas the sample irradiated 150 gray (Gy) after 30 days of harvest and kept at same temperature shows a 3.12 per cent loss in weight.

In case of irradiation at 500 gray (Gy), skin darkening occurred within the second week of storage with initial formation of black spots which further extended on the surface, the phenomenon accelerating with increase in storage temperature. This could be due to some disruption of the cells during radiation and subsequent incomplete healing of wounds in such irradiated potato tubers. The wound healing process involves suberization which is a deposition of suberin, a lipid phenolic polymer on the cell layers below the wound surface followed by formation of wound periderm or cork. Both this wound induced periderm formation and sprouting involve mitotic activity and cell division. (Metlitsky *et al*., 1957; Thomas 1982; Thomas and Delincee 1979). This accounts for the maximum loss in weight. Thus in case of tubers, 500 gray (Gy) of radiation is not recommended.

Specific gravity

The specific gravity of the tubers used in the study after harvesting from the field was recorded to be 1.081. A decrease in specific gravity was noticed after two months storage. It is evident that the factors like early irradiation, lower radiation dose and low storage temperature individually contribute in maintaining the specific gravity of the tubers. In case of tubers treated with 150 gray (Gy) after 15 days of harvest stored at 6 °C there is only 0.46 per cent change in specific gravity was detected whereas only 0.92 per cent change in specific gravity was observed in case of tubers treated with 150 Gy after 15 days of harvest and stored at 15 °C. The specific gravity of the sample irradiated with 500 gray (Gy) after 30 days of harvest and kept at ambient temperature showed highest (2.12 %) change in specific gravity among all samples irradiated; whereas samples left untreated in the ambient condition recorded 2.31 per cent change in specific gravity . It can be seen that samples stored at lower temperature shows comparatively less change in specific gravity for similar treatments.

Texture analysis

Texture is an important attribute of product as it affects processing and handling which in turn influences shelf life and consumer acceptance. Tubers lacking sufficient firmness and shear strength result in soft and shriveled potatoes and hence rejected by the customers. Texture of potato likewise correlates strongly with flavour, colour and other factors which determine the quality of processed products.

The peak force denotes the firmness. Shriveled tubers are soft and hence the probe requires less force for penetration into the tubers. The storage temperature along with the irradiation dosage has been found to have a significant relevance on the firmness. The samples irradiated with 500 gray (Gy) were found to be softer than the samples irradiated with 150 gray (Gy). The tubers irradiated with 150 gray (Gy) were reported to be firm with a relatively intact skin. The tubers irradiated with 500 gray (Gy) were found to be softer which may due to the fact that potato tubers irradiated with high rates of high energy exhibited an increase in soft rot and dry rot incidence in storage (Frazier *et al*., 2006). The effect of temperature on firmness is also significant. Storage temperature of 6° C shows maximum peak force values compared to storage temperature of 15° C for similar treatments. This implies that lower storage temperature is suitable in terms of preserving the firmness of the tubers. In case of untreated tubers kept in ambient condition, the peak force in case of firmness was observed to be 9.462 kg and peak force in case of shear was calculated to be 1.231 kg but for tubers treated with 150 Gy after 15 days of harvest stored at 6 °C the peak force in case of firmness was 12.965 kg and peak force in case of shear was 1.372 kg. Fig. 2 and 3 showed the variation in peak force in firmness and peak force in case of shearing for the different treatments.

Total soluble sugar (TSS) and starch

It is evident from the observations recorded and depicted in fig. 4, there was an increase in the sugar content in the tubers when stored at low temperature storage conditions. Our study reported a decrease in total sugar content upto 1.5 per cent in samples kept at higher storage temperature of 15^0 C compared to storage temperature of 6^0 C, thus corroborating the theory. Temperature appeared to play a critical role in influencing the carbohydrate reserve in potato samples when irradiated with either 150 gray (Gy) or 500 gray (Gy). Decreased temperature conditions have been implicated in causing a rise in reducing sugar concentration in a process known as 'cold-induced sweetening' (Matsurra-Endo *et al*., 2004). The increased reducing sugar content had a profound influence in elevating the total sugar content as was evident from our study. This result has a far reaching consequence; Kubicki (1964) reported that if less than 250 mg of reducing sugars is present per 100 g of potato tissue only then can the raw material can be used for chips production thus necessitating the decrease in reducing sugar content. A higher content of reducing sugars is also reported to result in browning. This observed increase in sugar content due to low temperature was in line with previous reports, the probable cause being that low temperature conditions affected the carbohydrate metabolism pathway thereby critically affecting the activities of several key enzymes. A significant increase in the activity of UDP-Glc pyrophosphorylase and sucrose phosphate enzyme may have resulted in conversion of starch to sucrose. This sucrose was further hydrolyzed to yield the reducing sugars by the action of the invertase enzyme leading to an increase in the total sugar content. In case of elevated temperatures conditions, the enzyme activity resulting in starch degradation remained restricted.

Again as evident from the study, the TSS level was found to be lower in the tubers irradiated 15 days after harvest in comparison to the tubers irradiated 30 days after harvest which was in accordance to that reported by Mahato and Das (2014). Irradiation treatment at initial low level of sugar content in fresh harvest might have influenced the ultimate total sugar accumulation pattern. Since less accumulation of sugars is desirable from the organoleptic point of view, irradiation at the early stages may be recommended.

Ascorbic acid

Ascorbic acid content in case of untreated samples was found to be 18.90 mg g^{-1} and it was evident from the results (Fig. 5) that there was a decrease in ascorbic acid content once irradiated. Delay in irradiation caused insignificant changes in ascorbic acid content, though the dosage of irradiation remained a prime criterion; higher dose of radiation decreased the ascorbic acid content upto 2 per cent. These findings were in accordance with Rezaee *et al*. (2011) and that of Wang and Chao (2003). From the results of this study it could be concluded that a higher dose of irradiation was responsible for degradation of ascorbic acid content. Tubers irradiated showed lower vitamin C levels during the early period of storage. However, as reported by Joshi *et al.* (1990) the trend reversed during further storage and at the end of 180 days irradiated tubers stored at 15°C recorded higher levels of ascorbic acid than control tubers stored at 2-4 °C. A positive correlation exists between ascorbic acid and maturation (Figueiredo *et al*., 2014; Fry, 1998 and Smirnoff, 1996) demonstrated that the presence of ascorbic acid resulted in decrease of pH of the medium, which activated expansions (cell wall proteins that induce cell wall extension and are thought to mediate pH-dependent cell expansion, thus preventing the accession of polysaccharides) which facilitated fruit maturation. It was believed that the lower level of this vitamin reduced the activity of these proteins, which caused a delay in ripening of the fruit. Irradiation thus delays ripening by lowering the concentration of ascorbic acid.

From this study it can be concluded that radiation within the first three months after harvesting is an effective treatment to inhibit sprouting in tubers. It was found that amongst all treatments, 150 gray (Gy) radiation was more effective and the tubers treated with 150 gray (Gy) radiation dosage and stored at 15^0 C produced the best results. Radiation treatment 500 gray (Gy) was detrimental for the tubers as it induced adverse changes in physical and biochemical quality parameters; the tubers lost their firmness and exhibited skin darkening with black spots making them unacceptable to the consumers. The elevated radiation dosage was responsible for loss in ascorbic acid content. Lower temperature storage also stimulated the conversion of starch into sugar and was thus responsible for the high sugar accumulation. It can thus be concluded that 150 gray (Gy) radiation dosage is more effective while a storage temperature of 15^0 C is preferred for preservation of the physico-chemical quality parameters and enhancing the shelf life of potatoes.

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