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Effects of gamma-irradiation on the morphological, structural, thermal and rheological properties of potato starches

Sandeep Singh[a], Narpinder Singh[a,*], Rajarathnam Ezekiel[b], Amritpal Kaur[a]

[a] Department of Food Science and Technology, Guru Nanak Dev University, Amritsar 143005, Punjab, India
[b] Central Potato Research Institute, Shimla 171001, India

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ABSTRACT

Changes in granule morphology, structural, thermal, gel textural and rheological properties of starches separated from two potato cultivars (Kufri Jyoti and Kufri Chipsona-2) caused by gamma-irradiation (Co^{60}, 0.01, 0.05, 0.1 and 0.5 kGy) were studied. A complete disorganization of the crystalline structure and carboxyl content of 0.09–0.11% was observed in starches irradiated at 0.5 kGy. Irradiation of starch increased gelatinization temperatures (onset-, peak- and conclusion-temperature) measured using DSC. Peak viscosity, trough viscosity, breakdown viscosity, final viscosity and gel hardness decreased while gel cohesiveness increased with the irradiation. Irradiation effect on gumminess, chewiness, adhesiveness and retrogradation of gels varied with the cultivar. Kufri Jyoti native and irradiated starches showed greater retrogradation as compared to Kufri Chipsona-2 native and irradiated starches. Difference in recrystallization of molecules as revealed from percent retrogradation and enthalpy of retrogradation amongst starch from two cultivars was also observed.

1. Introduction

Starches from different plant sources such as corn, potato, wheat and rice have been of interest in relation to their properties and applications. Like most other starches, potato starch also finds a wide range of applications in food industry in the form of thickening or binding agents. Native starches have some of the limitations such as low shear and thermal resistance as well as high affinity for retrogradation. The starches may need to be modified for their adaptability to the areas of application by improving the physico-chemical and functional characteristics. Gamma-irradiation can be a convenient tool for modification of polymer materials through cross-linking, grafting and degradation techniques. It has also been suggested as rapid and convenient modification technique which breaks large molecules into smaller fragments and is capable of cleaving glycosidic linkages (Kang et al., 1999; Yu & Wang, 2007). It has been shown that the chemical bonds of starch can be hydrolyzed by gamma irradiation leading to degradation of the polymeric chain. Besides food industry applications, the water-binding capacity and increased solubility/reduced viscosity of radiolyzed starch may be useful in applications for building, paper and textile materials (Kang et al., 1999). Modifications of starch and flour properties by gamma-irradiation have been reported in a number of studies. Maize and kidney bean flours irradiated with 10 kGy gamma-irradiation showed a decrease in pasting viscosity (Rombo, Taylor, & Minnaar, 2001). Gamma irradiation has also been used to modify functional properties of cowpea starch wherein a decrease in swelling and pasting properties has been reported (Abu, Muller, Doudu, & Minnaar, 2005). Kume and Tamura (1987) observed changes in the digestibility of raw tapioca and corn starch irradiated with 2.5 Mrad gamma-radiations. In our earlier studies, we discussed the changes in properties of starches extracted from irradiated potato tubers (Ezekiel, Rana, Singh, & Singh, 2007). The effect of gamma-irradiation on the properties of starch is of great importance, since starch constitutes as a component of majority of food products. The objective of present study was to investigate the effect of gamma-irradiation treatment (Co^{60}; 0.01, 0.05, 0.1 and 0.5 kGy) on the properties of starch separated from different potato cultivars.

2. Materials and methods

Tubers of two potato cultivars (Kufri Jyoti and Kufri Chipsona-2) from the 2009 harvest were procured from Central Potato Research Institute, Shimla. There were three samples (representing three replications) for each cultivar and treatment, and each sample consisted of 2 kg of tubers (weighing 75–125 g) taken randomly from a lot of 50 kg.

* Corresponding author. Tel.: +91 1832258826; fax: +91 183 2258820.
E-mail address: narpinders@yahoo.com (N. Singh).

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2.1. Starch isolation

The tubers were washed thoroughly, peeled and sliced into 2 mm thick slices using a rotary slicer and the slices were kept immersed in water containing 0.5% potassium meta-bisulphite to avoid browning. Defective slices were removed. The slices were ground thoroughly in a laboratory scale grinder to get fine slurry. The slurry was filtered through a muslin cloth and the residue on the muslin cloth washed repeatedly to recover starch. The filtrate was collected in a glass jar and left overnight for the starch to settle down. The supernatant liquid was decanted and the starch layer was washed repeatedly (4–5 times) with distilled water until the supernatant became clear. The starch cake was dried in a hot-air oven at 40 °C until dry. The dried starch was ground to a fine powder and kept in an airtight container at room temperature.

2.2. Irradiation treatment

The starch samples were sealed in a polythene bag and taken to the Nuclear Research Laboratory, Indian Agricultural Research Institute, New Delhi where the irradiation treatments were given using irradiator (Bhaba Atomic Research Centre, Mumbai) with Co^{60} source. Four doses of gamma-radiations, i.e. 0.01 kGy, 0.05 kGy, 0.1 kGy and 0.5 kGy were used. Native starch sample served as control.

2.3. Morphological properties

Scanning electron micrographs of starch samples separated from tubers of Kufri Chipsona-2 and irradiated with four doses of gamma-radiations were taken with a scanning electron microscope (Jeol JSM-6100, Jeol Ltd., Tokyo, Japan). A 1% starch suspension in ethanol was prepared and one drop of the suspension was taken on an aluminum stub and the starch was coated with gold:palladium (60:40). An accelerating potential of 15 kV was used during micrography.

2.4. Granule size distribution

Particle size distribution of the starches was measured by laser scattering using a Malvern Mastersizer Hydro2000S (Malvern Instruments Ltd., UK). The sample was added to the sample port to reach an obscuration to ∼15% and ultra-sonicated at 20% level for 1 min. The size distribution was expressed in terms of the volumes of equivalent spheres. The selected criteria were the percent volume (% vol) of granules with a diameter lower than 100 μm and the parameters d (0, 1), d (0, 5), and d (0, 9) expressed in micrometers.

2.5. X-ray diffraction

X-ray diffractograms of starch samples (equilibrated at 100% relative humidity, at 25 °C for 24 h) were recorded using an Analytical Diffractometer (Pan Analytical, Phillips, Holland), Cu Kα radiation with a wave length of 0.154 nm operating at 40 kV and 35 mA. XRD diffractograms were acquired at 25 °C over a 2θ range of 4° to 30° with a step size of 0.02° and sampling interval of 10 s.

2.6. Carboxyl content and pH

The carboxyl group content of irradiated starch was determined using the method of Chattopadhyay, Singhal, and Kulkarni (1997). The pH of starch slurry (40% w/v) was determined using a digital pH meter calibrated at 25 °C.

2.7. Physico-chemical properties of starch

Swelling power was determined using 2% (w/v) aqueous suspension of starch following the method of Schoch (1964). Apparent amylose content of starch samples was determined by the method given by Williams, Kuzina, and Hlynka (1970). Starch sample (20 mg db) was dispersed in KOH (0.5 M) and made up to 100 ml using distilled water. To an aliquot (10 ml) of the solution, 5 ml of HCl (0.1 M) and 0.5 ml of iodine reagent (0.1%) were added, diluted to 50 ml and the absorbance was measured at 625 nm. Apparent amylose content was derived from a standard curve using amylose and amylopectin blends.

2.8. Thermal and retrogradation properties

Thermal characteristics of isolated starches were studied by using a Differential Scanning Calorimeter-821e (Mettler Toledo, Switzerland) equipped with a thermal analysis data station. Starch (3.5 mg, dry weight) was loaded into a 40 μl capacity aluminium pan (Mettler, ME-27331) and distilled water was added with the help of Hamilton micro syringe to achieve a 30% (w/w) starch-water suspension. Samples were hermetically sealed and allowed to stand for 1 h at room temperature. The DSC analyzer was calibrated using indium and an empty aluminium pan was used as reference. Sample pans were heated at a rate of 10 °C/min from 30 to 100 °C. Onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c), and enthalpy of gelatinization (ΔH_{gel}) were calculated for the endotherms using Stare Software for thermal analysis Ver. 8.10.

The sample pans were kept at 4 °C for 1 week to study retrogradation properties. The pans were heated at a rate of 10 °C/min from 40 to 100 °C. Transition temperatures and enthalpy of retrogradation (ΔH_{ret}) was calculated for the endotherms. Percent retrogradation was calculated as the percent ratio of ΔH_{gel} and ΔH_{ret}.

2.9. Pasting properties

The pasting properties of starches were evaluated with Rapid Visco Analyzer (RVA-4, Newport Scientific, Warriewood, Australia). Viscosity profiles of starches from Kufri Jyoti and Kufri Chipsona-2 were recorded using starch suspensions (3:25, starch:water w/w). A programmed heating and cooling cycle was used where the samples were held at 50 °C for 1 min, heated to 95 °C at 6 °C/min, held at 95 °C for 2.7 min, before cooling from 95 to 50 °C at 6 °C/min and holding at 50 °C for 2 min. Parameters recorded were pasting temperature, peak viscosity, trough viscosity (minimum viscosity at 95 °C), final viscosity (viscosity at 50 °C), breakdown viscosity (peak-trough viscosity), and setback viscosity (final-trough viscosity).

2.10. Gel textural properties

A 10% (w/w) starch suspension was prepared and heated in a water bath at 90 °C for 15 min. The gels were immediately transferred into vials (20 ml) and stored at 4 °C for 24 h. Texture profile analysis was performed using TA.XT plus Texture Analyser (Stable Micro Systems, England) equipped with a 1 kg load cell, at room temperature. The vial was placed at the center of a heavy-duty platform (HDP/90). The gel was subjected to compression using a 5 mm diameter aluminum cylinder probe (SMS P/5) at a pre-test, test and post-test speed of 0.5 mm/s to a distance of 10 mm. The compression was carried out in two cycles to generate a force–time curve. Five replications were carried out and the textural parameters of hardness, springiness, cohesiveness, chewiness, gumminess and adhesiveness were calculated as described by Bourne (1978).

2.11. Dynamic rheology

The small amplitude measurements were also performed using a Haake Rheostress-6000 (Thermo Electron, Germany) to see the effect of holding at 10 °C for 1 h on rheological behavior of cooked

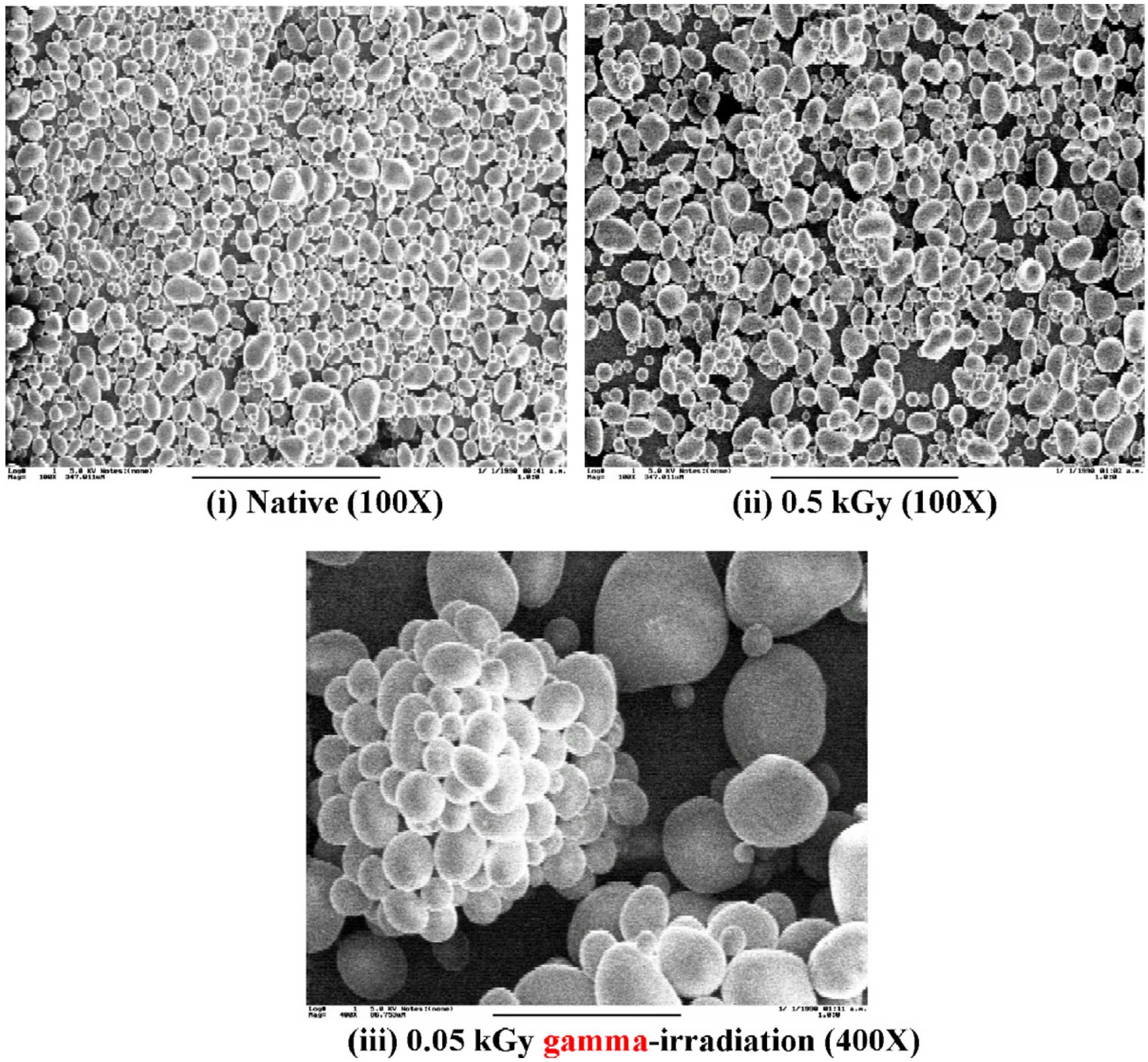

Fig. 1. Scanning electron micrograph (SEM) of Kufri Chipsona-2 starch.

starch pastes. Immediately after cooking on RVA as described above in section 2.9, the pastes were poured on the ram pre-heated at 50 °C. The paste was coated with silicone oil to avoid evaporation of water during experiment. A preliminary stress sweep test was carried out to determine the linear viscoelastic behavior. A PP35Ti parallel plate geometry and heating rate, stress and frequency of 2 °C/min, 1 Pa and 1 Hz, respectively, were used. The measurements were taken during cooling from 50 °C to 10 °C and then holding for 1 h at 10 °C.

2.12. Statistical analysis

All estimations were done in triplicate and the data were analyzed statistically using MSTAT (4.0 C) package.

3. Results and discussion

3.1. Granule characteristics

Scanning electron micrographs of native and gamma-irradiated starches revealed the presence of large oval and smaller spherical shaped starch granules (Fig. 1). Kufri Chipsona-2 starch granules had larger size as compared to granules of Kufri Jyoti starch. The mean granule size of Kufri Chipsona-2 (42.0 μm) and Kufri Jyoti (35.8 μm) starches measured agrees with our previous results (Singh, Isono, Srichuwong, Noda, & Nishinari, 2008). Irradiated starches showed presence of aggregated starch granules (Fig. 1ii and iii). The aggregation caused by irradiation has been attributed to weak starch–starch interactions as the aggregates were dispersible by ultra-sonication (Kume & Tamura, 1987). Among native and irradiated starches, larger granules (≥10 μm) constitute 93.8–94.5% to the total volume while smaller granules (<10 μm) constitute 5.5–6.2%. Kufri Jyoti starch showed higher proportion of small sized granules (6.2%) than Kufri Chipsona-2 (5.5%). Starch from irradiated Kufri Chipsona-2 (0.5 kGy) showed an increase in the proportion of small size granules (5.7%), however, the increase was statistically insignificant. Yu and Wang (2007) reported a similar increase in the proportion of small sized granules in rice starch irradiated at 5–10 kGy.

3.2. X-ray diffraction

X-ray diffractograms of native starches showed a typical B-type pattern consistent with our earlier studies (Singh, Nakaura, Inouchi, & Nishinari, 2008). Starches from both the cultivars showed strong reflections at $2\theta = 5.6^\circ$ and 17.1° (Fig. 2). Kufri Jyoti starch showed higher crystallinity compared to Kufri Chipsona-2 starch as indicated by higher intensity of the peaks ($2\theta = 5.6^\circ$ and

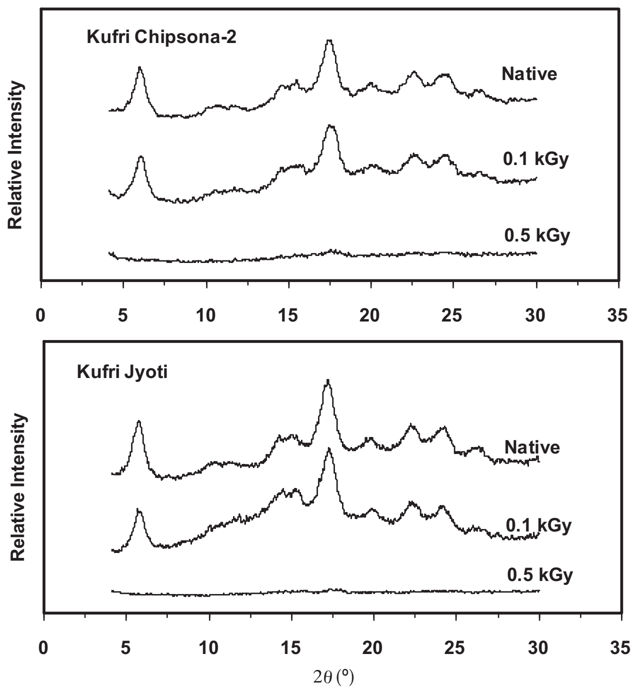

Fig. 2. X-ray diffraction patterns of native and irradiated (0.1 kGy and 0.5 kGy gamma-irradiation) potato starches.

17.1°). The intensity of peaks decreased with the increase in irradiation dose. Starches irradiated at 0.5 kGy did not show presence of any organized crystalline structure. Chung and Liu (2010) also observed a decrease in the relative crystallinity of potato and bean starches after gamma-irradiation at 50 kGy. The irradiation treatment caused greater decrease in crystallinity in Kufri Jyoti starch compared to Kufri Chipsona-2 at similar irradiation dose.

3.3. Carboxyl content

Native and irradiated starches at 0.01–0.1 kGy did not show any significant difference in the carboxyl content. The carboxyl content increased and as expected, the pH value decreased for both the cultivars at an irradiation dose of 0.5 kGy. Similar results have been observed in potato and bean starches when irradiated at 10 and 50 kGy (Chung & Liu, 2010). Kufri Jyoti showed higher carboxyl content (0.112%) and lower pH (5.3) than Kufri Chipsona-2 (0.09% and 5.5, respectively) at 0.5 kGy. Rayas-Duarte and Rupnow (1994) reported a pH decrease from 6.9 to 3.9 in Northern bean starch with the irradiation doses of 2.5–20 kGy. The changes by irradiation treatment have been attributed to the formation of free radicals and cleavage of large starch molecules (Sabularse, Liuzzo, Rao, & Grodner, 1991). Ghali, Ibrahim, Gabr, and Aziz (1979) reported formation of formic, acetic, pyruvic and glucuronic acids in starch as a result of irradiation. Hence, formation of degradation products such as carboxylic acids resulted in an increase in carboxyl content and a decrease in the pH value.

3.4. Physico-chemical properties

Kufri Jyoti starch showed higher swelling power (40.1 ml/g) than Kufri Chipsona-2 (38.1 ml/g). This may be attributed to the presence of higher proportion of small size granules in Kufri Jyoti than Kufri Chipsona-2. According to Kulp (1972), the small-granule starches from wheat had higher swelling power than the comparable regular ones. Swelling power of irradiated starches was dose dependant and showed a decrease with the increase in irradiation dosage. Starches irradiated with 0.5 kGy showed a significant decrease in the swelling power. A significant negative correlation (Fig. 3A) between swelling power and irradiation dose was observed ($r = -0.861$, $p \leq 0.005$). Kufri Jyoti showed higher percent decrease (12.2%) in swelling than Kufri Chipsona-2 (10.5%). Since swelling power is affected by the extent of interactions between starch chains within the amorphous and crystalline domains of the starch granules, the decrease in the swelling with irradiation could be attributed to the greater loss in crystallinity of Kufri Jyoti starches compared to Kufri Chipsona-2 at similar irradiation dose. Al-kahtani et al. (2000) observed a similar decrease in the swelling power of potato starch irradiated at 0.05–0.20 kGy. The apparent amylose content was higher in Kufri Jyoti (15.8%) than in Kufri Chipsona-2 (13.1%) as shown in Table 1. Irradiation treatment of starch caused an increase in the amylose content and a significant correlation of apparent amylose content with irradiation dose was observed ($r = 0.741$, $p \leq 0.05$) (Fig. 3B). Apparent amylose content in Kufri Jyoti and Kufri Chipsona-2 increased to 19.1% and 17.2%, respectively, with irradiation dose of 0.5 kGy. Increase in the amylose content of the starch extracted from irradiated corn has been reported earlier (Roushdi, Harras, El-Meligi, & Bassim, 1983).

3.5. Thermal properties

Kufri Jyoti had lower transition temperatures (T_o, 58.1 °C; T_p, 61.7 °C; T_c, 66.7 °C) compared to Kufri Chipsona-2 (59.0 °C, 63.0 °C and 67.8 °C, respectively). This difference in the transition temperatures could be attributed to the difference in the amylose content. McComber, Osman, and Lohnes (1988) reported that the starch granules from the mealy potatoes had lower gelatinization temperatures than waxy potatoes. Kufri Jyoti starch showed higher enthalpy of gelatinization (15.0 J/g) than Kufri Chipsona-2 (14.4 J/g). Higher enthalpy during melting of Kufri Jyoti starch could be attributed to the higher crystallinity. The enthalpy (ΔH_{gel}) during gelatinization determines the energy input and reflects the loss of molecular (double helical) order (Cooke and Gidley, 1992). The starch with lower and less perfect crystallinity has lower ΔH_{gel} (Inouchi, Glover, Sugimoto, & Fuwa, 1984). Irradiation (0.1 and 0.5 kGy) caused a slight increase in the enthalpies of the starches (Table 1) as shown in Fig. 3(C). Kufri Jyoti showed higher percent increase in the enthalpy (2.4%) than Kufri Chipsona-2 (1.7%) upon irradiation at 0.5 kGy. The gelatinization temperatures (T_o, T_p and T_c) also showed percent increase of 2.7%, 2.2% and 1.7%, respectively for Kufri Jyoti and 2.1%, 1.9% and 1.7%, respectively in Kufri Chipsona-2 at an irradiation dose of 0.5 kGy. The increase in the gelatinization temperatures with the increase in the irradiation dosage might be related to the destruction of relatively weak crystalline structures consequently resulting in higher stability of the remaining crystallites. The higher rise in gelatinization temperatures of Kufri Jyoti could be due to associations of amorphous amylose leading to greater stability of configuration in the granular structure (Lewandowicz, Jankowski, & Fornal, 2000).

3.6. Retrogradation properties

The retrogradation properties of native and irradiated starch gels were measured using DSC after 7 days of refrigerated storage (4 °C). Kufri Jyoti native starch displayed greater retrogradation (10.8%) than Kufri Chipsona-2 (9.3%). Transition temperatures and enthalpy (ΔH_{ret}) of retrogradation was significantly lower than the transition temperatures and ΔH_{gel} of gelatinization (Table 1). T_o, T_p and T_c of the retrograded starches ranged between 48.1–50.5 °C, 58.9–59.5 and 68.3–69.0 °C, respectively. Similar to the gelatinization behavior, Kufri Jyoti showed lower transition temperatures of retrogradation and higher ΔH_{ret} than Kufri Chipsona-2 (Table 1). The starches with higher ΔH_{ret} generally showed higher tendency

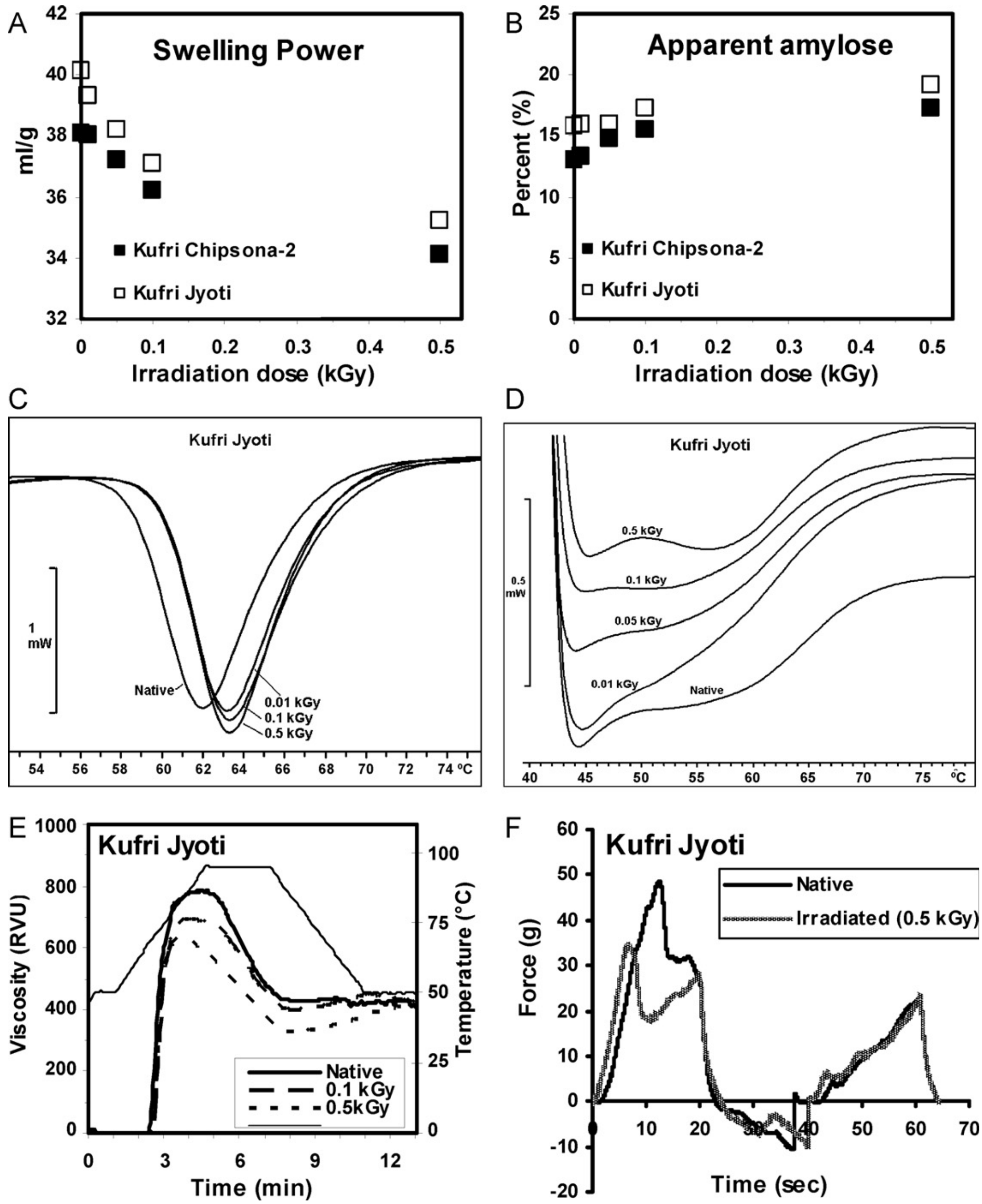

Fig. 3. Effect of gamma radiations on the properties of potato starches. (A) Swelling power; (B) apparent amylose content; (C) thermal; (D) retrogradation; (E) pasting profiles and (F) textural profile analysis of native and irradiated (0.5 kGy gamma-irradiation) potato starch gels.

to retrograde. The ΔH_{ret} is reported to be an indication of the unraveling and melting of double helices formed during storage and provides a quantitative measure of the energy transformation that occurs during the melting of re-associated amylopectin (Karim, Norziah, & Seow, 2000).

Irradiated starches from both the cultivars showed lower transition temperatures than their native starches (except for T_o of Kufri Jyoti irradiated at 0.5 kGy). The starch molecule recrystallisation occurs in a less ordered manner in stored starch gels than in native starches (Morikawa & Nishinari, 2000). Kufri Chisona-2 starch upon irradiation showed lower percent retrogradation and ΔH_{ret} while higher transition range (T_c–T_o) indicating lesser recrystallisation of the molecules during storage. In contrast, Kufri Jyoti starches showed an increase in percent retrogradation and enthalpy of retrogradation; and a decrease in transition range with the increase in the irradiation dosage (Fig. 3D). This indicates higher recrystallisation in Kufri Jyoti starch upon irradiation. Higher retrogradation in Kufri Jyoti may be attributed to the presence of higher proportion of amylose.

3.7. Pasting properties

The pasting profiles of native as well as irradiated starches are shown in Fig. 3(E). Native starches from both the cultivars showed similar pasting profiles, however Kufri Jyoti had higher breakdown (373 RVU) and lower final viscosity (402 RVU) than Kufri Chipsona-2 (321 RVU and 490 RVU, respectively). A progressive decrease in peak and breakdown viscosities was observed with the

Table 1
Swelling power, apparent amylose content, thermal and retrogradation properties of gamma-irradiated potato starches.

Cultivar	Treatment (kGy)	Swelling power (ml/g)	Apparent amylose (%)	Thermal properties				Retrogradation					
				T_o (°C)	T_p (°C)	T_c (°C)	ΔH_{gel} (J/g)	T_o (°C)	T_p (°C)	T_c (°C)	Range (T_c–T_o)	ΔH_{ret} (J/g)	% *R*
Kufri Chipsona-2	Native	38.1	13.0	59.04	63.04	67.82	14.37	50.47	58.95	69.00	18.53	1.34	9.32
	0.01	38.0	13.3	59.35	63.20	67.88	14.40	49.27	57.23	68.56	19.29	1.30	9.03
	0.05	37.2	14.7	59.68	63.53	68.50	14.42	48.58	57.11	68.23	19.65	1.13	7.84
	0.1	36.2	15.5	60.28	64.07	68.68	14.50	48.10	56.95	67.16	19.06	1.05	7.24
	0.5	34.1	17.2	60.30	64.24	68.94	14.62	46.96	56.44	66.51	19.55	0.91	6.22
Kufri Jyoti	Native	40.1	15.8	58.12	61.74	66.73	15.02	48.11	59.46	68.39	20.28	1.63	10.85
	0.01	39.3	15.9	59.53	62.92	67.82	14.97	46.03	56.96	66.38	20.35	1.7	11.36
	0.05	38.2	16.0	59.64	63.06	67.84	14.90	46.02	56.62	66.10	20.08	1.71	11.48
	0.1	37.1	17.3	59.63	63.07	67.84	15.00	47.47	56.11	65.26	17.79	1.76	11.47
	0.5	35.2	19.1	59.68	63.10	67.88	15.38	50.05	57.95	65.83	15.78	2.06	13.39
LSD (0.05)													
Cultivar		1.1	0.7	0.8	0.9	0.8	0.5	0.6	0.5	0.6	0.8	0.4	1.1
Treatment		0.6	0.3	0.5	0.4	0.6	0.3	0.4	0.5	0.5	0.5	0.4	0.9

increase in the irradiation dosage from 0.01 to 0.5 kGy (Table 2). Peak viscosity showed significant negative correlation with irradiation dose ($r = -0.863$, $p \leq 0.005$). The decrease in peak viscosity may be attributed to the breakdown of inter- and intra-molecular physical unions due to damage to the ordered structure of starch granules and consequent reduction in their swelling. The decrease in viscosity of starch with an increase in the level of gamma-irradiation has also been reported by other researchers (Chung & Liu, 2010;

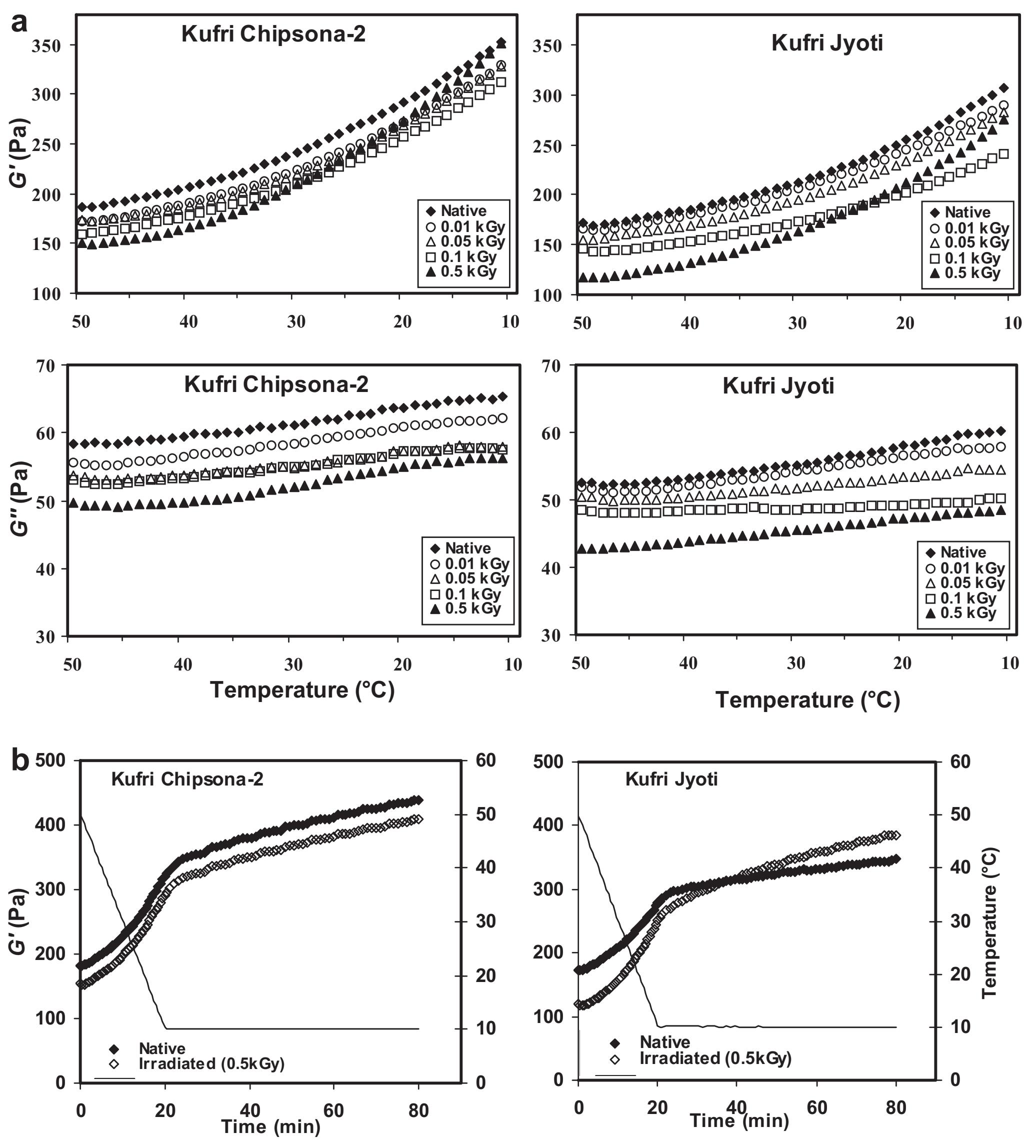

Fig. 4. (a) Storage modulus (G') and loss modulus (G'') of native and gamma-irradiated potato starches. (b) Changes in storage modulus (G') in native and gamma-irradiated (0.5 kGy) cooked starch pastes from Kufri Chipsona-2 and Kufri Jyoti cultivars during cooling (50–10 °C) and holding at 10 °C for 60 min.

Table 2
Pasting and textural properties of gamma-irradiated potato starches.

Cultivar	Treatment (kGy)	Pasting properties				Textural properties				
		Peak viscosity (RVU)	Break down (RVU)	Final viscosity (RVU)	Pasting temperature (°C)	Hardness (g)	Cohesiveness	Gumminess (g)	Springiness	Adhesiveness (gmm)
Kufri Chipsona-2	Native	798	321	490	66.95	48.41	0.423	20.45	1.017	75.22
	0.01	728	277	518	68.60	48.31	0.430	20.77	1.040	75.31
	0.05	712	278	513	68.60	47.27	0.459	21.71	1.018	75.74
	0.1	698	270	505	67.85	44.37	0.472	19.40	1.069	77.34
	0.5	638	249	462	67.80	34.58	0.537	18.57	0.989	84.68
Kufri Jyoti	Native	786	373	402	66.35	31.92	0.516	16.46	0.937	139.44
	0.01	752	341	426	67.75	30.11	0.519	15.63	0.925	138.54
	0.05	717	306	424	67.85	30.15	0.535	16.13	0.930	136.02
	0.1	696	298	420	67.90	23.07	0.547	12.63	0.920	134.95
	0.5	633	304	412	67.85	22.96	0.478	10.97	0.896	123.32
LSD (0.05)										
Cultivar		39.2	10.9	41.2	2.2	3.2	0.15	1.6	0.03	5.1
Treatment		11.8	6.9	23.0	0.9	1.0	0.03	0.8	0.02	1.5

Roushdi et al., 1983; Sabularse, Liuzzo, Rao, & Grodner, 1992). Final viscosity of irradiated starches (0.01–0.5 kGy) was higher than the respective native starch with the exception of Kufri Jyoti irradiated at 0.5 kGy. Pasting temperature of starches increased with irradiation treatment, though the increase was statistically insignificant. Starch from both the cultivars irradiated at 0.5 kGy showed lower final viscosity as compared to their native starch. Kang et al. (1999) reported that high doses of irradiation decreased the viscosity of starch paste while Yu and Wang (2007) attributed decrease in peak-, hot paste- and breakdown-viscosity to the decrease in size of the starch granules in rice caused by irradiation. Sung (2005) also reported reduction in pasting viscosities and setback of rice flour irradiated with 1 kGy radiation. The decrease in viscosity with irradiation may also be attributed to the degradation of starch to simpler molecules such as dextrins and sugars. Several other workers have also reported depolymerization of various starches following irradiation (Sabularse et al., 1992).

3.8. Textural properties

The texture of potato starch pastes can be described as stringy and cohesive (Swinkels, 1985). Kufri Jyoti gels showed higher hardness, gumminess, and springiness compared to those of Kufri Chipsona-2 starch (Table 2). Gel firmness is mainly caused by retrogradation of starch gels, which is associated with the syneresis of water and crystallization of amylopectins, leading to harder gels (Miles, Morris, Orford, & Ring, 1985). Irradiation treatment caused a decrease in gel hardness, gumminess and springiness in both the cultivars. Gels from starches treated with 0.5 kGy of irradiation showed the lowest hardness, gumminess, and springiness (Fig. 3F). The gel cohesiveness and adhesiveness increased with the increase in irradiation dosage, while chewiness showed an inconsistent trend. Gumminess of Kufri Chipsona-2 starch was not significantly affected upon irradiation treatment upto 0.1 kGy, however, a significant decrease at 0.5 kGy irradiation treatment was observed. Kufri Chipsona-2 gels showed a progressive increase while Kufri Jyoti gels showed a decrease in the adhesiveness with the increase in irradiation dosage. This could be attributed to higher retrogradation or recrystallization of molecules. The effect of irradiation on cohesiveness varied with the dosage, increased with the increase in irradiation to 0.1 kGy, followed by a decrease at 0.5 kGy treatment. The mechanical properties of gels from irradiated starch seem to be complex. Various factors, including the rheological characteristics of the amylose matrix, the volume fraction and the rigidity of the gelatinized starch granules, as well as the interactions between dispersed and continuous phases of the gel have been reported (Biliaderis, 1998).

3.9. Dynamic rheology

The changes in moduli of cooked starch pastes during cooling from 50 to 10 °C were measured. Both native and irradiated starches showed steep rise in G' during cooling from 50 to 10 °C, however, the increase was higher in Kufri Chipsona-2 compared to Kufri Jyoti. G' increased from 325 to 440 Pa in Kufri Chipsona-2 starch paste against an increase from 256 to 385 Pa in Kufri Jyoti starch when temperature was decreased from 50 to 10 °C. Both the moduli decreased with the increase in irradiation treatment. Among the irradiated starches, those treated with 0.5 kGy showed higher changes in G' in comparison to native as well as starches treated at lower levels of irradiation (Fig. 4a). G' increased to the greater extent as compared to G'' with the decrease in temperature in all the starches. The change in G' during 1 h of holding at 10 °C was also determined to see the retrogradation tendency of cooked starches. Kufri Chipsona-2 native and irradiated starches showed greater tendency towards retrogradation, as indicated by greater rise in

G' at 10 °C during 1 h of holding, as compared to their counterpart Kufri Jyoti native and irradiated starches (Fig. 4b). Starches irradiated at 0.5 kGy showed lower G' than observed for native starches during cooling from 50 to 10 °C. However, the G' of cooked paste from Kufri Jyoti starch irradiated at 0.5 kGy became greater than its counterpart native starch paste, after 20 min of holding at 10 °C. This may be attributed to greater structural destruction at higher level of irradiation (0.5 kGy) in Kufri Jyoti as compared to Kufri Chipsona-2, this corroborated with the X-ray results. Kufri Jyoti starch treated at 0.5 kGy irradiation dose showed higher carboxyl content and lower pH value as compared to Kufri Chipsona-2 starch treated at same irradiation dose. A faster increase in G' amongst cooked pastes from starches irradiated at 0.5 kGy level as compared to those from native starches during holding at 10 °C may be attributed to the presence of greater amount of soluble amylose in the former. The increase may also be attributed to the entanglement of solubilized amylose and the slow increase in G' over long period to the crystal formation of amylopectin. The increase in moduli during earlier stage has been suggested to depend on the chain entanglement in the amorphous regions since the entanglements behave as cross links with short life-times (Slade, Levine, & Finley, 1989).

4. Conclusions

Irradiation treatment of starch resulted in an increase in transition gelatinization temperatures (onset gelatinization temperature, peak temperature and conclusion temperature) and a decrease in pasting properties (peak viscosity, trough viscosity, break down viscosity and final viscosity). Irradiation effect on the crystallinity, textural and rheological properties of starch varied with the cultivar. Kufri Jyoti starch with greater crystallinity showed greater introduction of carboxyl group and reduction in pH upon irradiation as compared to Kufri Chipsona-2 starch with lower crystallinity, particularly, at higher level of irradiation (0.5 kGy). Unlike chemical treatments, which are time consuming, irradiation can be a quick and efficient method for modifying the properties of starch.

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