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Physicochemical, thermal and pasting properties of starch separated from γ-irradiated and stored potatoes

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Abstract

The morphological, thermal and pasting properties of starch separated from potatoes of three varieties (Kufri Chandramukhi, Kufri Jyoti and Kufri Chipsona-2), treated either with CIPC (isopropyl *N*-(3 chlorophenyl) carbamate) or γ-irradiation (Co^{60}, 0.1 and 0.5 kGy) and subsequently stored at 8, 12 and 16 °C for 90 days, were studied. Scanning electron microscopy (SEM) showed the presence of oval and irregular shaped starch granules with a diameter range of 15–16 µm. Mean granule size of starch separated from potatoes stored at 12 °C ranged from 18–25 µm and irradiation treatment resulted in an increase in the proportion of small size granules. The irradiation of potatoes with 0.5 kGy resulted in starch with significantly lower peak-, trough- and breakdown-viscosity as compared to starch from potatoes treated with either CIPC or 0.1 kGy irradiation. The irradiation of potatoes with 0.5 kGy caused a significant increase in setback and pasting temperature. Pasting temperature of starch was observed to vary with the storage temperature. Starch separated from potatoes stored at higher temperature showed lower pasting temperature and vice versa. The starch from potatoes stored at 8 °C showed higher peak-, trough- and breakdown-viscosity and lower setback. Peak viscosity increased and swelling volume decreased with increase in storage temperature. FTIR spectra showed that the starch from irradiated potatoes displayed a significant decrease in the intensity of the C–H stretch region between 2800 and 3000 cm^{-1}, which was observed to be irradiation dose-dependent, and higher with 0.5 than 0.1 kGy. However, a slight broadening of O–H stretch (3000–3600 cm^{-1}) in starches from irradiated potatoes was observed. The spectral changes caused by γ-irradiation were apparent in the O–H stretch (3000–3600 cm^{-1}), C–H stretch (2800–3000 cm^{-1}) and bending mode of water (1600–1800 cm^{-1}).

Keywords: Potato starch; Storage temperature; γ-Irradiation; Morphology, Pasting properties; Amylose; Phosphorus; Thermal properties

1. Introduction

Starch constitutes 65–80% of the dry weight of the potato tuber and is influenced by a number of factors, such as variety, weather, soil conditions, fertilization, irrigation, plant protection chemicals applied and time of planting and harvesting (Leszczynski, 1989; Smith, 1987). Besides cultural and environmental factors, storage also affects starch content and properties (Smith, 1987). Storage of potatoes is very important for the potato starch processing industry because fresh potatoes are available only for a few months in a year and the industry has to depend on stored potatoes for the remaining period. Effects of storage temperature on starch granule number and size (Golachowski, 1985; Jhonston, Urbas, & Khanzada, 1968; Mica, 1975), amylose content (Golachowski, 1985; Jhonston et al., 1968; Mica, 1975) and viscosity have been studied (Golachowski, 1985; Ridley & Hogan, 1976). Storage conditions are also reported to affect phosphorus, potassium and calcium contents of starch (Mica, 1976). The results of many of these studies are not comparable because of the differences in materials used and storage conditions (Golachowski, 1985).

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Potatoes stored at lower temperatures (4 °C or less) accumulate excessive reducing sugars and are therefore not suitable for processing (Burton, 1965; Van Es & Hartmans, 1987). When potatoes meant for processing are stored at temperatures of 8 °C or above, reducing sugar accumulation is lower but sprout growth takes place. Therefore, to check sprout growth, chemical sprout suppressants or irradiation have been used. CIPC (isopropyl *N*-(3 chlorophenyl) carbamate) is the commonly used chemical sprout suppressant, all over the world, on potatoes (Van Es & Hartmans, 1987). Irradiation treatment has also been tried in several countries for checking sprout growth (Thomas, 1984). Starch properties are known to be affected by irradiation. The effects of irradiation on particle size of starches (Kume & Tamura, 1987), swelling power (Al-kahtani et al., 2000; Deschreider, 1960; MacArthur & D'Appolonia, 1984), viscosity (Al-kahtani et al., 2000; Bachman, Witkowski, & Pietka, 1987; Sabularse, Liuzzo, Rao, & Grodner, 1992) and amylose content (Roushdi, Harras, El-Meligi, & Bassim, 1983; Sabularse et al., 1992) have been studied in starches extracted from different crops, with varying results. The objective of this investigation was to study some properties of starch separated from tubers of three potato varieties irradiated with two doses of γ-irradiation and stored at three different temperatures and to compare them with properties of starch separated from stored tubers treated with CIPC.

2. Materials and methods

2.1. Materials

Three varieties, namely Kufri Chandramukhi, a short duration variety (80–90 days) and Kufri Jyoti and Kufri Chipsona-2, medium duration varieties (90–110 days), were used in this experiment. All the three varieties are currently being used for processing in India. The crop was raised at the Central Potato Research Institute (CPRI), Modipuram, India (29°4′N, 77°46′E, 237 m above MSL) during 2003–2004, following a recommended package of practices. Planting was done in October, 2003 and harvesting in March 2004. The harvested tubers were taken to the Nuclear Research Laboratory, Indian Agricultural Research Institute, New Delhi where the irradiation treatments were given using an irradiator (Bhaba Atomic Research Centre, Mumbai) with Co^{60} source. Next day the irradiated and unirradiated tubers were brought to CPRI, Shimla, and stored in three walk-in-chambers maintained at three different temperatures, 8, 12 and 16 °C. The relative humidity was maintained at 90%. Un-irradiated tubers were treated with CIPC (isopropyl *N*-(3 chlorophenyl) carbamate), commonly known as chlorpropham to check sprout growth. CIPC was applied as a fog using a fogging machine (DYNA fog, USA). The dose used was 35 ml/ton of potatoes and the formulation used (called "Oorja", manufactured by United Phosphorus Ltd., Mumbai, India) contained 50% a.i. There were four treatments: (i) single application of CIPC, i.e. at the first sign of sprouting during storage; (ii) double application of CIPC (i.e. the first application at the first sign of sprouting and the second after 45 days of the first application); (iii) treatment with 0.1 kGy γ-irradiation before storage and (iv) treatment with 0.5 kGy γ-irradiation before storage. There were three replications for each variety and treatment and each replication consisted of 50 kg of tubers.

2.2. Reducing sugars

Ten tubers (weighing 75–125 g) were selected randomly from each replication before storage (un-irradiated tubers) and after 90 days of storage (DOS) with different treatments. The tubers were finely chopped, mixed thoroughly and 5 g were weighed and fixed in 80% isopropanol. Extraction was done by refluxing in 80% isopropanol and reducing sugars were estimated by Nelson's method (1944).

2.3. Starch isolation

Tubers were selected from each variety after 90 DOS with different treatments. There were three samples (representing three replications) for each variety and treatment at each observation and each sample consisted of 2 kg of tubers (weighing 75–125 g) taken randomly from a lot of 50 kg. 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 metabisulphite 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 maximum starch. The filtrate was collected in a tub and left overnight for the starch to settle. The supernatant liquid was decanted and the starch layer was washed repeatedly (4–5 times) with distilled water until the supernatant became transparent. 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 for further analysis. For scanning electron microscopy, only two varieties, namely Kufri Jyoti and Kufri Chipsona-2 stored at only one temperature, i.e. 12 °C, were used.

2.4. Morphological properties

Scanning electron micrographs of starch samples separated from tubers of two potato varieties viz. Kufri Jyoti and Kufri Chipsona-2 stored at 12 °C were taken with a scanning electron microscope (Jeol JSM-6100, Jeol Ltd., Tokyo, Japan). 1% starch suspension in ethanol was prepared and one drop of the suspension was taken on an aluminium stub and the starch was coated with gold palladium (60:40). An accelerating potential of 15 kV was used during micrography.

2.5. Physicochemical properties of starch

Swelling volume was determined using a 2% (w/v) aqueous suspension of starch, following the method of Schoch (1964). Amylose content of starch samples was determined by the method given by Williams, Kuzina, and Hlynka (1970). A starch sample (20 mg) was taken and 10 ml of 0.5 M L^{-1} KOH were added to it. The suspension was mixed thoroughly. The dispersed sample was transferred to a 100 ml volumetric flask and diluted to the mark with distilled water. An aliquot (10 ml) of this test solution was pipetted into a 50 ml volumetric flask and 5 ml of 0.1 M L^{-1} HCl were added, followed by 0.5 ml of iodine reagent. The volume was diluted to 50 ml and the absorbance was measured at 625 nm. Amylose content was read from a standard curve developed using amylose and amylopectin blends. Phosphorus content was determined by the method of Smith and Caruso (1964). A starch sample (500 mg) was digested in 5 ml of triacid ($HNO_3 + HClO_4 + H_2SO_4$; 9:4:1: ratio). The volume was made up to 25 ml and a 2 ml aliquot was taken. To this, 5 ml of ammonium molybdate, 1 ml of 1-2-4 aminonaphthol sulphuric acid were added and the volume was made up to 50 ml, mixed well and read at 660 nm after 30 min.

2.6. Thermal properties

Thermal characteristics of isolated starches were studied by using a Differential Scanning Calorimeter- 821^{e} (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 a Hamilton microsyringe to achieve a starch-water suspension containing 70% water. Samples were hermetically sealed and allowed to stand for 1 h at room temperature before heating in DSC. 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 20 to 100 °C. Thermal transitions of starch samples were defined as T_o (onset), T_p (peak of gelatinization) and T_c (conclusion), and ΔH_{gel} was referred to enthalpy of gelatinization. Enthalpies were calculated on starch dry basis.

2.7. Pasting properties

The pasting properties of starches were evaluated with a Rapid Visco Analyzer (RVA-4, Newport Scientific, Warriewood, Australia). Viscosity profiles of starches from different potato varieties were recorded using starch suspensions (6%, w/w; 28 g total weight). 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 (final-trough viscosity). All measurements were triplicated.

2.8. Fourier transform infrared (FTIR) spectroscopy

The FTIR spectra of starches separated from untreated and irradiated potatoes were acquired on a Shimadzu DR 2001 FTIR spectrophotometer (Shimadzu Corporation, Kyoto, Japan). Finely ground sample was intimately mixed with dried potassium bromide (KBr) powder (proportion 1:100 in weight) and pressed in a special die at 10,000 psi to yield a disc. Calibration was carried out using KBr as blank and the spectra were recorded within a range of 400–4000 cm^{-1}.

2.9. Statistical analysis

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

3. Results and discussion

3.1. Reducing sugar content

During storage, starch is converted into sugars (Smith, 1987). Thus, there was an increase in the reducing sugar content of tubers after storage. The reducing sugar content before storage varied from 66 to 81 mg/100 g f. wt and after 90 days of storage, it varied from 175 to 254, 164 to 270 and 145 to 263 mg/100 g f. wt in Kufri Chandramukhi, Kufri Jyoti and Kufri Chipsona-2, respectively (Table 1). Potatoes stored at 8 °C showed higher reducing sugar contents, which decreased with increase in storage temperature to 12 and 16 °C. Linnemann, van Es and Hartmans (1985) also observed higher reducing sugar content in CIPC-treated potatoes stored at 7 °C than when stored at 16 °C. The reducing sugar content has been reported to increase with irradiation of potatoes (Ussuf & Nair, 1972).

Table 1
Effect of CIPC, irradiation and storage temperature on reducing sugar content of different potato varieties before and after storage

Storage temperature (°C)	Treatment	Reducing sugars (mg/100 g f. wt)		
		Kufri Chandramukhi	Kufri Jyoti	Kufri Chipsona-2
8	CIPC-1	198	196	200
8	CIPC-2	195	200	206
8	0.1 kGy	228	270	210
8	0.5 kGy	254	264	263
12	CIPC-1	202	204	176
12	CIPC-2	175	200	153
12	0.1 kGy	220	210	186
12	0.5 kGy	209	224	194
16	CIPC-1	200	180	175
16	CIPC-2	192	164	145
16	0.1 kGy	193	178	196
16	0.5 kGy	202	214	217

LSD (0.05): variety, 7; temperature, 7; treatment, 8.

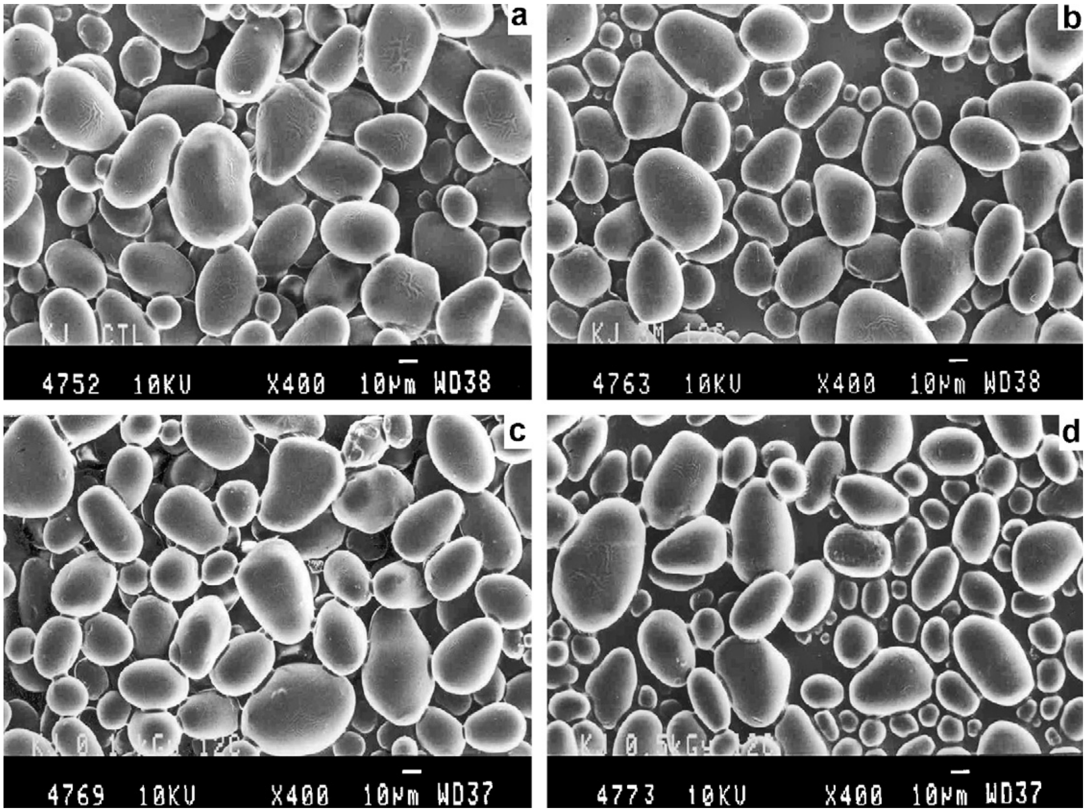

Fig. 1. Scanning electron micrograph (SEM) of starch separated from tubers of variety Kufri Jyoti before storage (a) and after 90 days of storage at 12 °C with CIPC (b), 0.1 kGy gamma irradiation (c) and 0.5 kGy gamma irradiation (d) treatments.

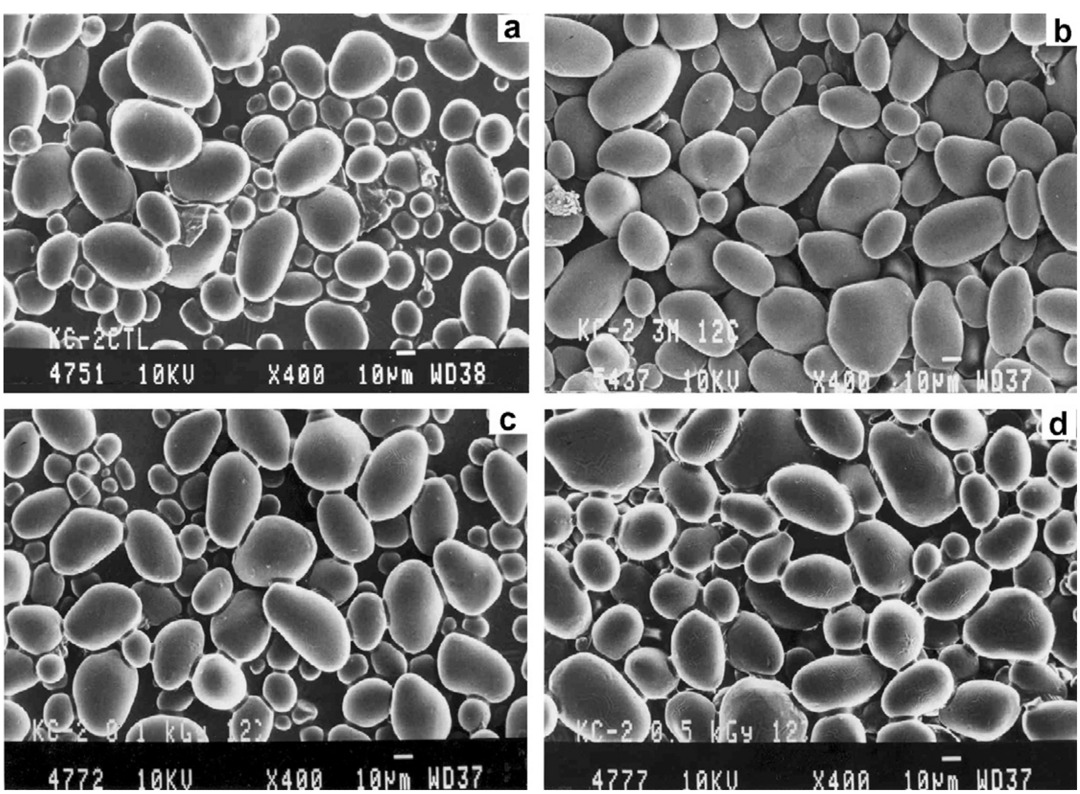

Fig. 2. Scanning electron micrograph (SEM) of starch separated from tubers of variety Kufri Chipsona-2 before storage (a) and after 90 days of storage at 12 °C with CIPC (b), 0.1 kGy γ-irradiation (c) and 0.5 kGy γ-irradiation (d) treatments.

3.2. Morphological properties of potato starch

Variation in starch granule size is shown in Figs. 1 and 2. Kufri Jyoti and Kufri Chipsona-2 starch showed granule diameters from 6 to 38 μm (mean 15 μm) and 6 to 36 μm (mean 16 μm), respectively. Kufri Jyoti potato, with CIPC treatment and subsequent storage at 12 °C for 90 days, resulted in starch with a granule diameter range of 6–52 (25 μm) whereas those treated with 0.1 and 0.5 kGy showed diameters of 6–42 (23 μm) and 6–38 μm (18 μm), respectively. The γ-irradiation treatment of potatoes resulted in an increase in the proportion of small size granules. Some of the granules in Chipsona-2 starch became fused when irradiated at higher dose level of 0.5 kGy. Yu and Wang (2007) reported that irradiation treatment of rice at doses of 5, 8 and 10 kGy increased the amount of small size granules. These changes have been attributed to the free radicals generated by irradiation, cleaving large starch molecules, and some starch granules became fractured along the cleaved molecules (Grant & G'Appolonia, 1991; Sabularse, Liuzzo, Rao, & Grodner, 1991). Jhonston et al. (1968) reported that the number of granules of size <22 μm diameter decreased and granules sized between 31 and 44 μm diameter increased after 80 days of storage at 4 °C. Contrarily, Golachowski (1985) observed a decrease in the proportion of granules with >35 μm diameter and an increase in smaller granules (<20 μm) after 12 weeks of storage at 8 and 20 °C.

3.3. Physicochemical properties of starch

Swelling volume decreased significantly with increase in storage temperature, Kufri Jyoti showed higher swelling than did the other two varieties (Table 2). Potato starch

Table 2
Effect of CIPC, irradiation and storage temperature on amylose content, phosphorus content and swelling volume of starch separated from different potato varieties

Variety	Storage temperature (°C)	Treatment	Swelling volume (ml/g)	Amylose (%)	Phosphorus content (%)
Kufri Chandramukhi	8	CIPC-1	40	17.7	0.07
	8	CIPC-2	41	17.1	0.07
	8	0.1 kGy	43	18.7	0.08
	8	0.5 kGy	41	18.6	0.09
	12	CIPC-1	42	17.1	0.07
	12	CIPC-2	34	16.7	0.08
	12	0.1 kGy	37	18.6	0.08
	12	0.5 kGy	37	18.9	0.12
	16	CIPC-1	39	18.7	0.10
	16	CIPC-2	35	17.1	0.09
	16	0.1 kGy	39	17.9	0.08
	16	0.5 kGy	30	18.7	0.08
Kufri Jyoti	8	CIPC-1	42	17.0	0.08
	8	CIPC-2	42	17.9	0.07
	8	0.1 kGy	40	17.9	0.07
	8	0.5 kGy	38	20.2	0.12
	12	CIPC-1	42	15.6	0.13
	12	CIPC-2	42	17.9	0.11
	12	0.1 kGy	37	18.8	0.08
	12	0.5 kGy	36	19.1	0.10
	16	CIPC-1	39	16.5	0.10
	16	CIPC-2	35	17.6	0.08
	16	0.1 kGy	38	17.7	0.06
	16	0.5 kGy	35	19.1	0.07
Kufri Chipsona-2	8	CIPC-1	41	16.8	0.07
	8	CIPC-2	40	17.1	0.07
	8	0.1 kGy	38	19.0	0.08
	8	0.5 kGy	37	19.5	0.08
	12	CIPC-1	42	16.7	0.12
	12	CIPC-2	33	16.9	0.08
	12	0.1 kGy	38	19.6	0.13
	12	0.5 kGy	35	18.4	0.09
	16	CIPC-1	40	17.5	0.08
	16	CIPC-2	33	17.2	0.09
	16	0.1 kGy	36	17.5	0.10
	16	0.5 kGy	34	19.4	0.08
LSD (0.05)	Variety		1.0	0.2	0.01
	Temperature		1.0	0.2	0.01
	Treatment		1.6	0.3	0.02

is known to have a higher swelling volume than other starches (Singh, Singh, Kaur, Sodhi, & Gill, 2003) and indeed this is 10–100 times higher than that observed for starches of other crops (Leszczynski, 1989). The higher swelling volume and swelling power of potato starch has been attributed to the presence of negatively charged phosphate groups, which are responsible for the swelling of starch granules (Singh et al., 2003; Swinkels, 1985). Swelling volume of starch decreased significantly with CIPC and irradiation treatment in all three varieties and the decrease was observed to be dose-dependent. The starch from CIPC-2- and 0.5 kGy irradiation-treated potatoes showed greater than did starch from CIPC-1- and 0.1 kGy-treated potatoes. Al-kahtani et al. (2000) also observed a decrease in swelling power of starch separated from potatoes irradiated with 0.05–0.20 kGy and stored at 5 and 20 °C. In starch extracted from corn irradiated with 1, 2, 5 and 10 Mrad, the swelling power increased up to 2 Mrad and then decreased rapidly (Roushdi et al., 1983). The amylopectin fraction of starch is believed to be primarily responsible for swelling (Tester & Morrison, 1990) and the decrease in swelling volume may be attributed to a reduction in the amylopectin fraction with irradiation. De kerf, Mondelaers, Lahorte, Vervaet, and Remon (2001) found a significant reduction in the amylopectin fraction of various starches with irradiation. Amylose content of starch separated from different potato varieties varied from 15.6% to 22% (Table 2). Kufri Chandramukhi starch showed significantly lower amylose content than did starch from other varieties. Singh and Singh (2003) also observed varietal differences in amylose content of potato starch. The starch separated from tubers stored at higher temperature had lower amylose content. Golachowski (1985) also observed lower amylose content

Table 3
Effect of CIPC, irradiation and storage temperature on thermal properties of starch separated from different potato varieties

Variety	Storage temperature (°C)	Treatment	T_o (°C)	T_p (°C)	T_c (°C)	ΔH_{gel} (J g^{-1})
Kufri Chandramukhi	8	CIPC-1	59.2	62.7	67.4	14.9
	8	CIPC-2	58.9	62.6	67.2	15.1
	8	0.1 kGy	60.4	63.8	68.4	10.9
	8	0.5 kGy	62.0	65.2	69.8	14.6
	12	CIPC-1	60.3	64.1	68.9	14.0
	12	CIPC-2	61.2	64.4	68.7	13.7
	12	0.1 kGy	61.8	65.4	69.5	14.1
	12	0.5 kGy	60.2	63.6	67.7	15.1
	16	CIPC-1	62.3	66.1	70.1	14.0
	16	CIPC-2	60.4	64.1	67.9	12.8
	16	0.1 kGy	60.1	63.7	69.0	15.1
	16	0.5 kGy	61.8	65.8	73.7	13.4
Kufri Jyoti	8	CIPC-1	62.4	65.2	70.4	14.1
	8	CIPC-2	62.5	65.3	70.5	14.3
	8	0.1 kGy	61.5	64.2	69.3	12.7
	8	0.5 kGy	61.8	64.3	67.5	13.4
	12	CIPC-1	62.2	66.1	70.4	14.2
	12	CIPC-2	61.6	65.0	69.4	14.7
	12	0.1 kGy	60.9	65.6	71.0	13.0
	12	0.5 kGy	61.2	65.2	69.9	13.8
	16	CIPC-1	61.9	65.7	70.2	13.9
	16	CIPC-2	63.6	67.6	72.4	13.1
	16	0.1 kGy	61.3	65.2	69.9	13.3
	16	0.5 kGy	62.6	65.9	70.4	14.3
Kufri Chipsona-2	8	CIPC-1	60.5	64.4	69.9	14.2
	8	CIPC-2	61.1	64.6	69.5	13.8
	8	0.1 kGy	61.3	64.6	69.0	12.8
	8	0.5 kGy	61.4	65.0	69.5	11.0
	12	CIPC-1	61.7	65.2	70.3	14.2
	12	CIPC-2	60.5	64.7	70.2	13.7
	12	0.1 kGy	63.0	65.8	69.9	15.0
	12	0.5 kGy	62.1	65.4	70.1	15.1
	16	CIPC-1	62.8	64.3	70.9	14.5
	16	CIPC-2	61.4	64.5	69.3	13.9
	16	0.1 kGy	60.7	63.8	69.5	15.7
	16	0.5 kGy	61.2	65.9	70.5	14.2
LSD (0.05)	Variety		0.4	0.4	0.3	0.2
	Temperature		0.5	0.3	0.4	0.2
	Treatment		ns	0.4	0.3	0.2

in starch separated from potatoes stored at 8 and 20 °C for 12 weeks. Starch separated from potatoes treated with either CIPC-1 or CIPC-2 did not show any significant difference in amylose content. Starch separated from potatoes irradiated with 0.5 kGy showed higher amylose content than did that irradiated with 0.1 kGy. Yu and Wang (2007) observed a decrease in apparent amylose content by 2.86%, 6.58%, 9.87% and 12.2%, respectively, with 2, 5, 8 and 10 kGy doses of irradiation treatment of rice. Amylose content in corn starch has been reported to increase with irradiation treatment up to 2 Mrad (Roushdi et al., 1983). Sabularse et al. (1992) reported that amylose content of rice starch was not greatly affected by irradiation treatments of 1, 2 and 3 kGy. The phosphorus content varied from 0.07% to 0.13% (Table 2) and was consistent with the phosphorus content of 0.063–0.115% for starch in European and North American potato varieties (Veselovsky, 1940). Kufri Chandramukhi starch showed a significantly lower phosphorus content than did starch from the other two varieties.

3.4. Thermal properties

The results of DSC analysis of starches separated from different potato varieties are summarized in Table 3. The onset gelatinization temperature (T_o), peak temperature (T_p) and conclusion temperature (T_c) of starches separated from different potato varieties ranged from 59.3 to 67.2 °C, 62.6 to 70.8 °C and 62.8 to 70.8 °C, respectively. Kufri Chandramukhi starch showed the lowest transition temperatures and that may be due to the lower crystallinity. The irradiation of potatoes at 0.5 kGy caused an increase in

Table 4
Effect of CIPC, irradiation and storage temperature on pasting properties of starch separated from different potato varieties

Variety	Storage temperature (°C)	Treatment	Peak viscosity (cP)	Trough viscosity (cP)	Breakdown (cP)	Final viscosity (cP)	Setback (cP)	Pasting temperature (°C)
Kufri Chandramukhi	8	CIPC-1	3420	2556	863	3000	444	67.0
	8	CIPC-2	3774	2783	990	3183	400	67.0
	8	0.1 kGy	3696	2980	715	3422	440	68.6
	8	0.5 kGy	3584	3276	308	3882	606	68.6
	12	CIPC-1	2614	2270	344	3085	815	67.0
	12	CIPC-2	2405	2330	75	3320	990	69.4
	12	0.1 kGy	2374	2262	112	3442	1180	69.4
	12	0.5 kGy	2682	2174	508	2753	580	66.9
	16	CIPC-1	2820	2566	255	4650	2085	70.1
	16	CIPC-2	2832	2138	694	2620	480	68.4
	16	0.1 kGy	3395	2272	1123	2728	456	66.9
	16	0.5 kGy	2570	2420	152	4054	1635	72.6
Kufri Jyoti	8	CIPC-1	4813	2615	2198	3009	394	67.1
	8	CIPC-2	3774	2870	904	3379	509	67.9
	8	0.1 kGy	3145	2650	496	3110	460	69.4
	8	0.5 kGy	2620	2590	30	3686	1095	69.4
	12	CIPC-1	3870	3040	830	3514	473	70.2
	12	CIPC-2	2580	2538	42	3834	1296	70.2
	12	0.1 kGy	2866	2732	134	3746	1014	70.1
	12	0.5 kGy	2639	2559	80	3800	1243	69.3
	16	CIPC-1	1818	1562	256	2980	1418	69.3
	16	CIPC-2	3190	2836	355	5249	2413	71.8
	16	0.1 kGy	3572	2517	1055	2886	370	70.1
	16	0.5 kGy	2214	2027	187	3470	1443	70.3
Kufri Chipsona-2	8	CIPC-1	3757	2935	822	3406	470	68.6
	8	CIPC-2	3300	3022	277	3655	633	68.5
	8	0.1 kGy	2805	2684	120	3405	720	67.7
	8	0.5 kGy	2058	1880	178	3018	1138	69.3
	12	CIPC-1	2340	2227	113	3380	1152	68.6
	12	CIPC-2	2030	1978	52	3370	1392	68.5
	12	0.1 kGy	2905	2836	70	3636	800	69.4
	12	0.5 kGy	2038	1860	177	3152	1290	68.5
	16	CIPC-1	2704	2392	312	3317	925	69.3
	16	CIPC-2	3074	2312	762	2903	590	68.6
	16	0.1 kGy	3201	2579	622	3013	434	69.4
	16	0.5 kGy	2242	2020	220	3110	1088	68.6
LSD (0.05)	Variety		120	100	30	125	40	ns
	Temperature		125	90	30	ns	45	ns
	Treatment		110	90	40	120	50	0.5

T_p and T_c of their resultant starches. T_p and T_c of starches were observed to be dependent on storage temperature of potatoes. The starches separated from potatoes stored at higher temperature showed higher transition temperatures (T_o, T_p and T_c). The maize starches with more amorphous regions had lower transition temperatures (Singh, Inouchi, & Nishinari, 2006), while the starches with higher crystallinity were observed to have higher transition temperatures, as well as higher gelatinization enthalpies. Barichello, Yada, Coffin, and Stanley (1990) also reported that higher transition temperatures resulted from higher degree of crystallinity, which provides structural stability and makes the granules more resistant to gelatinization. Their results also revealed that starches with long branch chain length amylopectin displayed higher gelatinization enthalpy, indicating that more energy was required to gelatinize the crystallites of long chain length. The difference in ΔT among the starches from different potato cultivars may be due to the presence of crystalline regions of different strengths in the granules (Banks & Greenwood, 1975). Vasanthan and Bhatty (1996) and Gunaratne and Hoover (2002) also reported that variability in ΔT values in starches was due to differences in the degree of heterogeneous crystallites, which have slightly different crystal strengths.

3.5. Pasting properties

Pasting temperature of starch separated from potatoes of three varieties varied from 67.0 to 68.55 °C; the highest was observed for Kufri Jyoti starch. Kufri Chandramukhi starch showed significantly lower pasting temperature, peak- and trough-viscosity than did starches from the other two varieties (Table 4). The irradiation of potatoes at 0.5 kGy caused a significant effect on the pasting properties of their starches. The irradiation of potatoes with 0.5 kGy resulted in starch with significantly lower peak-, trough- and breakdown-viscosity than the starches from their counterpart potatoes treated with either CIPC or 0.1 kGy irradiation (Fig. 3). The irradiation of potatoes of different varieties with 0.5 kGy caused a significant increase in setback and pasting temperature of starch. Pasting temperature of starch was observed to vary with the storage temperature. Starch separated from potatoes stored at higher temperature showed lower pasting temperature and vice versa. The starch separated from potatoes stored at 8 °C showed higher peak-, trough- and breakdown-viscosity and lower setback. These changes in pasting properties may be attributed to increase in the proportion of small size granules and breakdown of intra- and intermolecular physical unions. Kang et al. (1999) reported that high doses of irradiation decreased the viscosity of starch paste and Hayashi (1996) reported similar results for starch-containing products. Grant and G'Appolonia (1991) and Sabularse et al. (1991) pointed out that irradiation damaged the ordered structure of starch granules. Yu and Wang (2007) attributed a decrease in peak-, hot paste- and breakdown-viscosity to the decrease in size of the starch granules

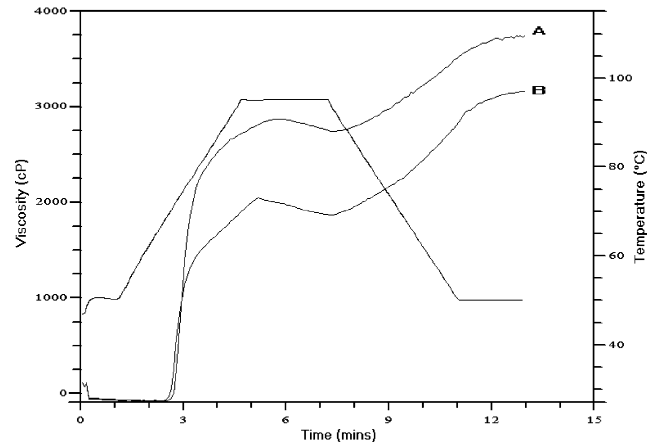

Fig. 3. Rapid visco analyzer (RVA) curves of starches separated from irradiated potatoes ($A = 0.1$ kGy, $B = 0.5$ kGy).

in rice caused by irradiation. Bao and Corke (2002) reported a negative correlation between viscosity and irradiation dosage, using rices with different sensitivities to irradiation. The effects observed could be attributed to the breakdown of intra- and intermolecular physical unions, as stated earlier, because the low radiation doses supply sufficient energy to produce changes in the molecular spatial arrangements; the energy used is lower than that required to break the molecule chains (Adeil Pietranera & Narvaiz, 2001). Sung (2005) also reported reduction in peak viscosity, hot paste viscosity, cold paste viscosity and setback upon treatment of rice flour with 1 kGy radiation. The decrease in viscosity of starch with an increase in the level of γ-irradiation has also been reported by other researchers (Roushdi et al., 1983; Sabularse et al., 1992). Irradiation has also been reported to reduce the viscosity of starch separated from potatoes irradiated with 0.05–0.20 kGy and stored at 5 and 20 °C (Al-kahtani et al., 2000). The decrease in viscosity with irradiation may be attributed to 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; Sokhey & Hanna, 1993; Wu, Shu, Wang, & Xia, 2002).

3.6. FTIR

The changes in FTIR spectra of starch separated from irradiated potatoes are shown in Figs. 4 and 5. The starches separated from irradiated potatoes showed a significant decrease in intensity of the C–H stretch region between 2800 and 3000 cm^{-1}. This decrease was observed to be irradiation dose-dependent, and higher in starch separated from potatoes treated with 0.5 kGy than in starch treated with 0.1 kGy. The starches separated from irradiated potatoes showed a slight broadening in O–H stretch (3000–3600 cm^{-1}). The spectral changes in starches caused by γ-irradiation of potatoes were also apparent in the O–H

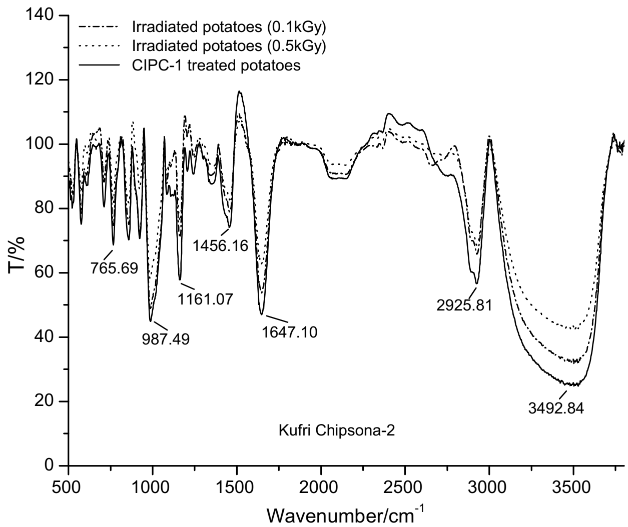

Fig. 4. FTIR spectra of starches separated from CIPC and γ-irradiated potatoes (cv-Kufri Chipsona-2).

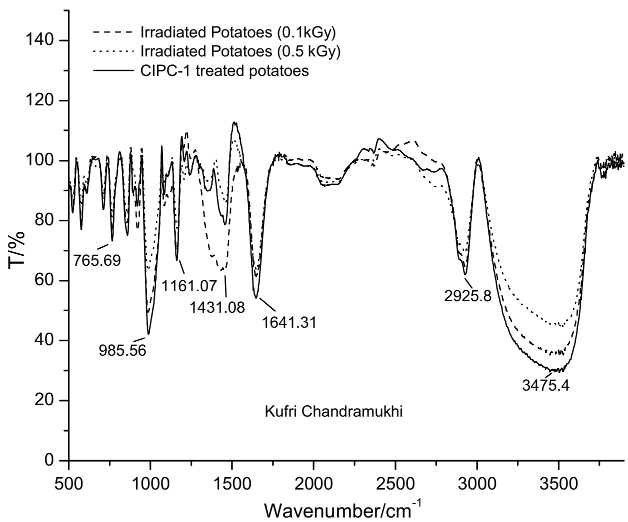

Fig. 5. FTIR spectra of starches separated from CIPC and γ-irradiated potatoes (cv-Kufri Chandramukhi).

stretch (3000–3600 cm^{-1}), C–H stretch (2800–3000 cm^{-1}) and bending mode of water (1600–1800 cm^{-1}). These changes may be attributed to the breaking of chemical bonds by irradiation (called radiolysis) resulting in formation of unstable reactive agents, which subsequently converted to stable end-products. Radiolysis of water present in potatoes resulted in formation of hydroxyl radicals, free hydrogen atoms and aqueous electrons, which react with different constituents present in foods. Similar effects of γ-irradiation, at 3, 5 and 10 kGy doses, on starch gels have been reported using FT-Raman spectroscopy (Kizil & Irudayaraj, 2006).

4. Conclusions

The physicochemical, thermal and pasting properties of starches separated from three varieties of potatoes, stored at different temperature after CIPC and irradiation treatment, were investigated. The average diameter of starch granules and the percentage of larger granules increased after storage at 8, 12 and 16 °C whereas irradiation treatment resulted in an increase in the proportion of small granules. The irradiation of potatoes with 0.5 kGy resulted in starch with significantly lower peak-, trough- and breakdown-viscosity than starch from potatoes treated with either CIPC or 0.1 kGy irradiation. The irradiation of potatoes with 0.5 kGy caused significant increases in setback and pasting temperature. Pasting temperature of starch was observed to vary with the storage temperature. Starch separated from potatoes stored at higher temperature showed lower pasting temperature and vice versa. The starch from potatoes stored at 8 °C showed higher peak-, trough- and breakdown-viscosity and lower setback. FTIR spectra confirmed significant effects of irradiation treatment of potatoes on the properties of their starches. Irradiation treatment, usually given to check sprout growth in potato tubers during storage at higher temperatures, brought about significant changes in the properties of their starches and hence suitability for different products.

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