Food Science and Engineering
http://ojs.wiserpub.com/index.php/FSE/

Research Article

Potato Nutritional Quality Loss Due to Bruising: Need Attention During Handling

Bandana Kaundal[1*], Vineet Sharma[1], Sukhwinder Singh[2], Brajesh Singh[3], Manoj Kumar[1]

[1]ICAR-Central Potato Research Institute Campus, Modipuram, Meerut-250 110 (UP), India
[2]ICAR-Central Potato Research Station, Jalandhar-144 003 (PB), India
[3]ICAR-Central Potato Research Institute, Shimla-171 001 (HP), India
E-mail: bandana.biochem@gmail.com

Received: 24 September 2021; **Revised:** 04 March 2022; **Accepted:** 15 March 2022

Abstract: Bruising of potatoes is the main problem in potato processing industry and is the major cause of consumer dissatisfaction in terms of economic loss. Potato quality is adversely affected by bruise damage. In general practice, when tubers are harvested, handled, packed and transported, it is impossible to prevent them from falling and damage. After falling, external symptoms sometimes are not visible but the damage may affect the nutritional quality. Sorting and grading contribute 0.98 kilograms per quintal giving a percentage of 16.50%. Packaging and storage yield 0.45 and 1.18 kilograms per quintal owing 7.49 and 19.79% respectively. Therefore, the aim of the experiment was to find out the effect of bruising on processing and nutritional quality of processing varieties *viz.* Kufri Chipsona-1, Kufri Chipsona-3, Kufri Frysona and table purpose varieties *viz.* Kufri Surya and Kufri Pukhraj by simulating different impacts (control, 30, 60 and 90 cm). Results revealed that all processing varieties resulted in deterioration of chip score due to an increase in reducing sugars concentration after impact (45 and 60 days of storage, ambient storage). Weight dropping to potato tubers from a height of 60 cm and 90 cm and their storage up to 60 DOS (days of storage) gave comparably high reducing sugars. Impact from a height of 30, 60 and 90 cm, irrespective of all the varieties reported having higher phenol content. Reduction in weight loss was directly proportional to the height of impact and quality deteriorated further during storage. Mechanical damage to cell walls, caused loss of quality through texture softening, followed by decreasing texture firmness of potato.

Keywords: *Solanum tuberosum*, bruising, quality, biochemical parameters, impact, storage

1. Introduction

The potato (*Solanum tuberosum* L.) is one of the most important agricultural crops grown for human consumption after wheat, maize and rice. Potato has the ability and adaptability to be processed and transformed in many products in temperate, tropical and as well as subtropical regions of the world, giving tuber the potential to impact several aspects of health and nutrition. Potato is a bulky, semi-perishable crop and bruising is a serious problem in the potato industry. It has been observed that the effects of bruising are felt by every handler and consumer of potatoes and is a major economic matter of concern. Besides that, the mechanized processes used from harvesting to final usage too generate a lot of bruises in the potato. It has been reported by field observations that 40 to 50% of horticultural crops

DOI: https://doi.org/10.37256/fse.3120221173

(including root, tuber crops, fruits and vegetables) produced are lost before they can be consumed, chiefly due to high rates of bruising, water loss and decay during postharvest handling [1]. Quantities of potatoes are harvested to provide a continuous supply of potatoes to the industry and processed for various products for consumption. Processable potatoes with bruising damage are unacceptable in the market. Potatoes after bruising reduce demand and are passed back on the grower in terms of lower prices, and also increase storage losses. Approximately > 80% of potato is produced in the Indo-Gangetic plains of Uttar Pradesh. Harvesting coincides with the increase in temperature during the month of March, as a result, water loss and respiration rates increase, which leads to weight loss. In the United Kingdom, 64% of the harvested potato are bruised [2], whereas, in India, postharvest losses due to bruising transportation ranged from 30-40% [3]. Due to low adoption of mechanization, mostly potatoes are handled manually and transportation and storage are done in 50 kg capacity bags, which are manhandled resulting in unavoidable bruisings [4]. So potatoes must be protected possibly their quality postharvest. Potato is harvested, transported up to storage place through local means by hired/local labours, keeping lots and sudden dropping off from their heads or dropping from trolley from height. The greater the drop height, the more bruising occurs and it also leads to a shift in damage from internal black spot to external shatter bruise. Keeping all these problems into consideration, an experiment was designed assuming the impact that occurs on the potato after sudden drop from a certain height. The objective of this experiment was to study the effect of bruising with different heights of impact set-up on processing varieties on quality parameters and postharvest losses.

2. Materials and methods

Samples were procured from field experiments conducted at ICAR-Central Potato Research Institute Campus, Modipuram (29.1° N latitude, 77.92° E longitude, and an altitude of 300 m above mean sea level) following all recommended cultural practices. Five potato varieties *viz.* Kufri Chipsona-1, Kufri Chipsona-3, Kufri Frysona, Kufri Surya and Kufri Pukhraj were raised in three replications. The crop was planted during the month of October and harvested after full maturity K. Chipsona-1, (K. Chipsona-3, K. Frysona) at 110 days, whereas Kufri Pukhraj and Kufri Surya were harvested at 90 days. Harvesting was done manually using hand-hoe to prevent any type of damage to potato.

2.1 *Simulation of potato bruise (by modified dropping bolt method)*

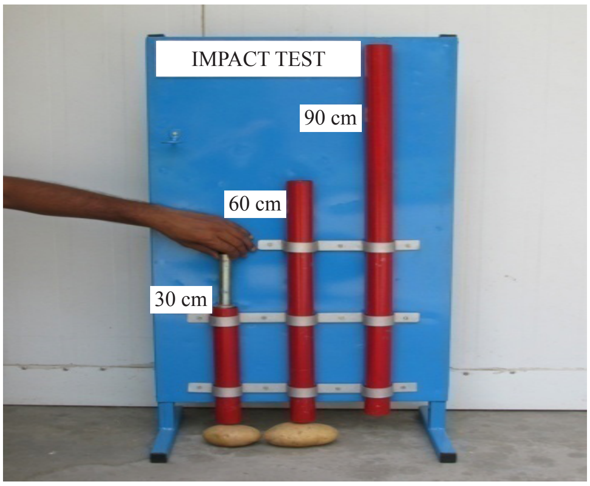

Figure 1. Dropping bolt impact instrument

For giving a controlled impact to the tubers, bolt drop tests were conducted through modified method. For conducting these tests mechanism was fabricated in which three iron pipes having different heights (30, 60 and 90 cm, each having 40 mm internal diameter) on the iron board were fitted with the help of clamps keeping the base distance same. Tubers were kept one by one (50 tubers) at the lower end of the tube horizontally on the cemented floor. For giving impact artificially, a mild steel bolt with hexagonal head (182.6 g in weight with diameter of 13 mm, and height of 11.5 mm) was dropped from a height of 30, 60 and 90 cm having energy of 0.635 J, 1.270 J and 1.905 J, respectively, inside the tubes onto the horizontal surface of the tuber (Figure 1).

Control of each variety was kept without any impact. Bruised along with control potato were analyzed after impact for physiological (weight loss, number of cracks and peeling losses) and biochemical parameters (dry weight, chip colour, reducing sugars, sucrose, total free amino acids, phenols and ascorbic acid). Different impact treated potatoes were stored for 30, 45 and 60 days sampling and stored (triplicate) in a laboratory at 25 ± 0.5 C and 95 ± 0.5% relative humidity (RH).

2.2 *Physiological parameters*

2.2.1 *Number of cracks*

For counting the number of cracks on the whole tuber, a solution of 2% catechol solution was prepared. Five bruised or damaged potatoes of each sample were dipped in this solution for 10 minutes and allowed to dry. Due to enzymatic oxidation (phenolic) and catechol, blue colour is developed. Blue colour make its entry into cracked or bruised tubers and is clearly visible for counting [5].

2.2.2 *Peeling losses*

Peeling losses were evaluated by removing the skin of the potatoes with the help of a peeler manually having a depth of 1.5 mm in a single peel at the impact site. Strokes of peeling were given till the bruise or cut was removed from the surface.

2.2.3 *Weight loss*

For the weight loss study, bruised tubers were weighed before storage from each sample. Weight of each cultivar after 30, 45 and 60 days of storage with different impact treatment was recorded.

Thereafter losses on a weight basis were estimated using the formula.

Weight loss % = (weight before storage-weight after storage)*100)/weight before storage

2.2.4 *Preparation of chips*

Processing grade potatoes were sliced (1.75 mm) with the help of an electric potato chip slicer. Slices were then washed with cold water to remove starch and minimize sticking. After washing, slices were dried by spreading on blotting paper to remove excess water from the surface of the slices and were deep fried at 180 C till bubbling stopped. Frying medium used was refined sunflower oil. Chip color was subjectively assessed by a visual score of the scale of 1 to 10, where 1 denoted highly acceptable and score up to 3.0 was considered acceptable [6] whereas, chip colour score > 3.0 was unacceptable.

2.3 *Biochemical parameters*

2.3.1 *Sample preparation*

For analysis of dry matter and biochemical parameters, five potatoes were cut longitudinally into two halves. The halves of potatoes were cut into small cubes and mixed properly. Cut cubes were used directly for dry matter content whereas for biochemical attributes 10 g cubes were weighed, put into 80% isopropyl alcohol, refluxed twice at 70 C and filtered. After removing alcoho, evaporation volume was made up to 100 mL with distilled water. Each sample was used further analysis (reducing sugar, sucrose, phenol, total free amino acid and ascorbic acid content).

2.3.2 *Determination of dry matter*

After chopping the sample, mix thoroughly, fill (50 to 100 gram) the pre-weighed aluminum dish, weigh the chopped samples along with the aluminum dish and put it into a hot air oven at 65-70 degrees celsius for drying. For drying, keep the sample in the oven at least for 72 hours until the constant weight was obtained [7].

Dry matter (%) can be calculated using the following expression:

Dry matter (%) = (dry weight/Fresh weight)*100

2.3.3 *Reducing sugars*

Reducing sugars after extraction in 80% isopropanol, were analyzed by the suggested method [8]. To the supernatant (0.2 mL), alkaline copper tartrate reagent was added and the content was boiled for 10 min, cooled and 1 mL of arsenomolybdate reagent was added. Developed blue color was photometrically measured at 620 nm.

2.3.4 *Sucrose*

Sucrose was analyzed according to the anthrone method [9]. To 0.1 mL of the 80% ethanol extract, 0.1 mL of 30% aqueous potassium hydroxide was added and kept in a boiling water bath for 10 minutes. The samples were cooled and 3.0 mL of anthrone reagent was added and kept at 40 C for 10 minutes. The absorbance was read at 620 nm.

2.3.5 *Phenols*

To the extract (1 mL), 0.5 mL Folin-Ciocalteau reagent (1 N) was added followed by addition of 2 mL of sodium carbonate (20%). Blue colored complex was measured for its absorbance at 650 nm [10] against a reagent blank.

2.3.6 *Ascorbic acid*

Ascorbic acid was extracted with 4% (w/v) oxalic acid and then it was oxidized to dehydro-ascorbic acid by the addition of bromine water. 2, 4-Dinitrophenylhydrazine was added to the oxidized products and the red color of resultant osazone was photometrically measured at 540 nm [11].

2.3.7 *Total free amino acids*

The total free amino acid was estimated using the ninhydrin method [12]. 0.1 mL extract sample was taken and 1 mL of ninhydrin solution was added into it. Volume was made 2 mL with distilled water and placed in a water bath in boiling water for 20 minutes. The tubes were cooled to room temperature and after adding 5 mL of the diluents the absorbance was measured at 570 nm in a spectrophotometer using blank.

2.4 *Statistical analysis*

The statistical analysis of experimental data was performed using statistical software 'Cropstat' developed by the International Rice Research Institute, (https://cropstat.software.informer.com/7.2/) using a completely randomized block design. The analysis variates were the dry weight, weight loss, number of cracks, peeling losses, Reducing sugar, Sucrose, phenols, total free amino acid and ascorbic acid. Factors taken were variety (VA), days of storage (DS), impact height (HE). A balanced ANOVA was applied to choose the relevant independent variables influencing the dependent variable using 5% significance level.

3. Results

3.1 *Number of cracks*

The number of cracks in variety Kufri Chipsona-1 with the impact at 30 cm height was less than two, whereas from the impact at height of 60 and 90 cm cracks were reported more than two. In general, the severity of cracks is pronounced with the height impact in all the varieties. At '0' day, the lowest number was noticed in Kufri Pukhraj (1.64), followed by Kufri Chipsona-1 (1.76), K. Chipsona-3 (1.92) and Kufri Surya (1.9) with 30 cm impact height. Maximum cracks were reported in variety Kufri Frysona (5.2) followed by Kufri Pukhraj (5.0) both at 90 cm height (Figures 2 and 3).

Figure 2. Severely cracked tubers after 45 days impact damage

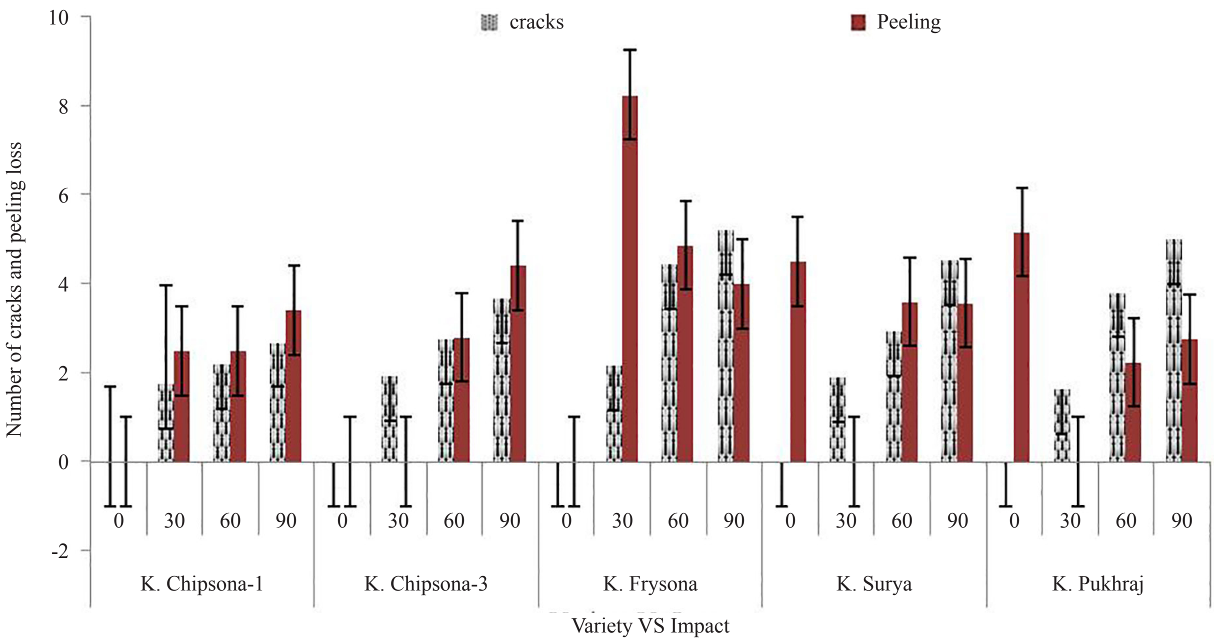

Figure 3. Number of cracks and peeling loss after impact from different heights

3.2 *Peeling loss*

It was observed that peeling losses were negligible in all the varieties without nil impact. A maximum percentage of peel loss was observed, in general, with a maximum impact at a height of 90 cm (Figure 3). In the variety, Kufri Frysona, maximum peeling loss (8.24%, 30 cm height) was monitored followed by K. Pukhraj (5.16%). Bruised potatoes were peeled and so peeling losses were more.

3.3 *Effect on weight loss*

Table 1. Effect of impact on dry weight and weight loss (%) after different days of storage

Variety	Height (cm)	Dry weight (%)				Weight loss (%)			
		Days of storage							
		0	30	45	60	0	30	45	60
K. Chipsona-1	0	23.24	24.28	22.60	21.49	6.04	7.15	10.40	13.47
	30	23.98	25.6	17.97	16.38	8.38	10.07	13.52	14.90
	60	23.09	24.23	15.68	12.83	15.30	17.32	18.82	22.70
	90	23.76	20.44	13.43	12.23	16.23	20.14	25.31	27.75
K. Chipsona-3	0	22.33	22.47	23.99	23.36	6.91	11.17	14.29	14.55
	30	22.87	23.62	25.75	23.87	8.44	14.36	15.97	22.79
	60	23.01	21.02	21.30	18.47	10.01	14.93	19.86	21.32
	90	22.15	21.5	20.71	18.33	20.71	30.5	33.06	51.31
K. Frysona	0	22.71	23.06	22.31	22.59	5.85	10.19	12.35	13.96
	30	22.58	24.62	20.69	20.91	7.42	10.68	13.89	16.99
	60	21.98	23.48	20.04	18.64	9.94	17.36	20.17	21.76
	90	22.31	21.3	18.01	17.82	19.57	20.80	25.65	32.25
K. Surya	0	19.51	19.8	17.11	18.91	4.20	7.47	12.05	12.17
	30	19.25	19.77	17.92	15.14	7.43	10.00	13.73	22.48
	60	19.63	18.06	16.71	15.7	10.88	15.08	16.82	23.11
	90	18.32	16.48	15.27	14.46	16.40	29.86	34.06	44.31
K. Pukhraj	0	16.94	16.69	15.63	15.41	8.56	10.07	11.05	14.11
	30	16.87	16.49	15.46	13.15	10.80	13.66	14.36	18.91
	60	16.54	15.95	15.05	12.40	14.57	14.52	20.56	20.72
	90	16.97	15.47	14.25	11.34	16.51	17.53	31.93	35.07

*	S.Em. ±	CD (0.05)	S.Em. ±	CD (0.05)
VA X DS	(0.04)	(0.10)**	(0.23)	(0.65)**
VA X HE	(0.04)	(0.10)**	(0.23)	(0.65)**
DS X HE	(0.03)	(0.09)**	(0.21)	(0.58)**
VA X DS X HE	(0.07)	(0.21)**	(0.46)	(1.29)**

**VA: Variety, DS: Days of Storage, HE: Height

In general irrespective of all the varieties, the maximum reduction in weight loss was observed with a maximum height of impact (90 cm) which increases with the duration of storage. Studies have shown that the weight loss percent varies considerably from one variety to another depending on the height of the impact as well as days of storage. Among the processing varieties both Kufri Chipsona-1 and Kufri Frysona registered less reduction in weight as compared to another varieties (Table 1).

3.4 *Effect on biochemical constituents*

3.4.1 *Chip colour*

Potato chip color was subjectively assessed by visual scoring of the color on the scale of 1 to 10, where 1 denoted highly acceptable (white) with a score up to 3 was in acceptable limits and score 10 was considered unacceptable. Results in Table 2 indicated that acceptable chip colors were recorded in almost all the processing varieties i.e. Kufri Chipsona-1, Kufri Chipsona-3 and Kufri Frysona as compared to variety K. Pukhraj. Further sampling after impact from 30, 60 and 90 cm subjected to storage resulted in deterioration of quality of chip colour in terms of dark colors which were not acceptable. In variety, Kufri Chipsona-1, impact from 30 cm and storage at ambient temperature after 30 and 45 days of storage resulted in 4.0 and 6.0 chip scores, respectively. A sampling at 30 days of storage combined with 60 cm impact was found to be scored 5.3. Further, sampling at 60 days, increased chip score. The interaction (X) between variety, days of storage, variety X height, Days of storage X height and variety X days of storage X height was found to be significant.

3.4.2 *Dry matter*

It is evident from the data presented in Table 1 that dry matter was found maximum at initial stages in all the varieties. Dry weight decreased with the increasing impact and duration of storage. Loss in dry matter was more pronounced after 45 days of sampling in all tested varieties. Observations on dry matter of variety indicated that there was meagre loss in varieties Kufri Chipsona-3 and Kufri Frysona due to impact except at 60 days of storage with impact from 90 cm height. Kufri Surya and Kufri Pukhraj at different days of sampling after impact also showed a loss in dry matter.

3.4.3 *Reducing sugars*

Results in Table 2 revealed that in varieties K. Chipsona-1 and K. Chipsona-3 reducing sugar content remains within acceptable range till 45 days. Impact stress at a height of 30, 60 and 90 cm, resulted in an increase in reducing sugars. The varietal difference was also found in the case of Kufri Chipsona-1, Kufri Surya and Kufri Pukhraj, reducing sugar increases with days of storage whereas in varieties K. Chipsona-3 and Kufri Frysona it decreased with days of storage from 30 to 45 days. Variety Kufri Chipsona-1 and Kufri Chipsona-3 after impact from a height of 30 to 60 cm accumulated acceptable reducing sugars, but impact or stress from height from 90 cm was not suitable for sugars.

3.4.4 *Sucrose*

The effect of variety and interaction between variety and impact height was significant (Table 2). The duration of storage had a significant effect on the sucrose content of potato tubers. Sucrose content in general, was initially high at zero days of sampling and it was found to be decreased at 60 days. Sucrose content showed a dip in values at 45 days of storage after impact.

Table 2. Effect of impact on chip colour, reducing sugars and sucrose after different days of storage

Variety	Height (cm)	Chip colour score				Reducing sugar (mg/100 g FW)				Sucrose (mg/100 g FW)			
		Days of storage											
		0	30	45	60	0	30	45	60	0	30	45	60
K. Chipsona-1	0	2.2	3.4	3.8	4.2	48.88	57.36	81.57	172.15	251.40	286.96	254.27	237.49
	30	2.6	3.6	4.7	5.4	51.89	58.48	120.02	229.18	262.66	265.12	232.24	229.44
	60	2.5	4.7	5.3	6.8	49.63	115.11	149.86	222.83	240.16	225.84	211.27	193.01
	90	2.8	5.9	7.3	7.3	56.12	130.8	236.26	234.25	218.00	202.55	172.92	161.91
K. Chipsona-3	0	2.3	2.3	2.7	3.7	77.50	70.31	88.49	113.58	191.87	185.50	184.31	183.96
	30	2.6	3.8	3.8	4.1	75.23	123.96	84.06	156.48	178.51	176.77	166.79	162.85
	60	2.6	4.1	4.7	4.7	80.59	129.03	83.18	204.69	170.18	167.43	155.20	146.94
	90	2.7	5.4	5.4	5.9	78.14	133.29	118.41	228.06	169.34	155.66	145.40	135.42
K. Frysona	0	2.3	3.1	3.1	5.1	128.79	137.80	71.03	182.60	351.14	321.42	301.65	281.26
	30	2.2	4.2	4.5	5.9	135.21	158.95	139.00	192.02	348.86	291.19	259.22	236.41
	60	2.3	5.1	5.5	6.2	142.89	202.88	163.06	220.25	298.86	245.46	204.52	186.33
	90	2.4	5.3	5.7	6.4	150.63	206.50	191.29	209.23	297.16	238.35	183.03	144.30
K. Surya	0	2.8	3.2	3.1	5.6	64.50	91.46	143.03	208.10	220.96	213.98	212.16	212.11
	30	3	4.2	4.7	5.8	67.36	153.81	190.41	210.28	226.87	207.92	210.11	195.19
	60	3	5.8	5.1	6.2	62.13	170.38	189.12	218.00	210.69	194.43	176.38	167.69
	90	3.2	6.5	6.2	6.7	70.19	201.59	194.03	242.29	209.49	166.52	156.50	151.63
K. Pukhraj	0	5.7	5.9	6.3	7	194.63	183.73	194.21	322.50	396.54	395.69	315.02	288.24
	30	6.3	6.6	6.8	7.5	185.36	228.70	211.00	423.87	360.95	323.70	251.35	162.79
	60	6.3	6.8	8.1	7.9	195.67	239.07	238.99	436.66	352.22	316.42	224.67	141.80
	90	6.2	7.5	8.3	9	190.39	245.19	246.96	424.11	335.15	286.15	195.20	129.80

*	S.Em. ±	CD (0.05)	S.Em. ±	CD (0.05)	S.Em. ±	CD (0.05)
VA X DS	(0.07)	(0.19)**	(0.12)	(0.33)**	(2.03)	(5.72)**
VA X HE	(0.07)	(0.19)**	(0.12)	(0.33)**	(2.03)	(5.72)**
DS X HE	(0.07)	(0.17)**	(0.11)	(0.30)**	(1.82)	(5.12)**
VA X DS X HE	(0.14)	(0.39)**	(0.24)	(0.66)**	(4.06)	(11.44)**

**VA: Variety, DOS: Days of storage, HE: Height

3.4.5 *Phenols*

Table 3. Effect of impact on total free amino acid, phenols and ascorbic acid after different days of storage

Variety	Height (cm)	Total free amino acid (mg/100 g)				Phenols (mg/100 g)				Ascorbic acid (mg/100 g)			
		Days of storage											
		0	30	45	60	0	30	45	60	0	30	45	60
K. Chipsona-1	0	226.9	253.4	377.42	608.3	34.3	35.2	62.6	62.80	31.46	25.37	24.15	20.60
	30	321.8	509.9	622.79	966.2	34.9	43.4	80.4	76.38	26.59	23.87	16.13	14.39
	60	198.5	707.1	653.04	1044.5	35.6	45.3	99.3	120.94	26.44	23.01	14.39	13.73
	90	259.8	763.7	1021.51	1011.7	36.4	81.1	106.4	135.28	23.73	19.44	10.24	8.78
K. Chipsona-3	0	521.6	644.9	634.29	883.4	28.3	29.4	42.0	63.65	26.73	24.38	22.81	18.12
	30	533.5	671.7	621.51	870.2	29.8	34.0	69.9	77.91	26.67	22.61	22.00	14.87
	60	601.9	752.2	767.62	890.7	28.5	59.5	86.4	109.14	26.58	20.49	17.84	11.22
	90	548.3	870.2	829.82	1074.3	29.0	73.4	97.5	134.60	25.89	19.87	12.36	7.56
K. Frysona	0	606.7	681.5	608.31	743.7	31.2	38.1	60.9	78.00	24.80	23.11	20.73	15.87
	30	714.2	711.8	808.95	1043.2	32.6	52.9	68.8	83.26	24.19	21.22	17.56	10.48
	60	600.5	710.1	949.52	1077.7	31.9	62.7	89.2	85.46	22.18	21.60	16.34	8.75
	90	613.3	735.6	1025.77	1116.9	34.9	72.8	108.4	113.13	22.80	19.13	10.73	6.09
K. Surya	0	458.1	601.1	737.70	791.3	39.6	43.6	67.9	72.65	33.00	31.70	24.91	17.00
	30	413.6	628.3	1059.42	1093.0	35.3	51.4	76.8	84.79	32.37	31.70	20.56	13.41
	60	498.1	690.1	1053.46	1104.1	40.1	86.7	131.7	86.74	30.18	25.97	18.56	13.66
	90	501.2	698.1	1061.13	1109.6	39.7	113.3	133.5	142.16	30.54	22.75	17.58	11.63
K. Pukhraj	0	786.7	710.5	875.19	893.7	24.3	33.4	42.0	35.48	18.36	16.93	15.12	12.07
	30	711.5	544.4	914.48	945.2	25.6	40.7	48.6	63.65	18.64	16.20	12.87	8.12
	60	698.3	589.1	983.6	1029.1	24.9	45.3	67.4	75.70	17.34	14.84	10.36	7.80
	90	725.8	766.7	1056.44	1241.9	26.4	46.8	72.2	90.22	16.49	14.67	8.14	7.07

*	S.Em. ±	CD (0.05)	S.Em. ±	CD (0.05)	S.Em. ±	CD (0.05)
VA X DS	(0.02)	(0.06)**	(0.37)	(1.05)**	(0.28)	(0.78)**
VA X HE	(0.02)	(0.06)**	(0.37)	(1.05)**	(0.28)	(0.78)**
DS X HE	(0.02)	(0.05)**	(0.33)	(0.94)**	(0.25)	(0.70)**
VA X DS X HE	(0.04)	(0.11)**	(0.75)	(2.11)**	(0.55)	(1.55)**

**VA: Variety, DOS: Daysofstorage, HE: Height

At zero day of sampling, all the varieties under test maintained low phenols. Impact severity increased phenols concentration in all the stored potatoes. The content increased maximum at 90 cm impact height after 30 days of storage. Maximum increase (4.6 times more than initial) from its initial value (28.36 to 134.60 mg/100 g fresh weight) was found in variety Kufri Chipsona-3 followed by K. Surya (39.67 to 142.16 mg/100 g fresh weight) at 90 cm height (Table 3).

3.4.6 *Total free amino acids*

Total free amino acids remained low in control where the impact was not applied. In most of the treatments, total free amino acid was found to increase slightly at 60 and 90 cm height impact on potato tubers. In variety Kufri Surya it increased rapidly after 45 days. At the initial stage minimum content was estimated in K. Chipsona-1(198.56 mg/100 g fresh weight) and maximum in Kufri Pukhraj (786.75 mg/100 g fresh weight). Non-processing variety K. Pukhraj resulted in maximum total free amino acids (1241.96 mg/100 g fresh weight) in the treatment of 90 cm impact height at 60 days storage (Table 3). The results showed there was an increase in the level of total free amino acid corresponding to the bruise.

3.4.7 *Ascorbic acid*

Maximum ascorbic acid or vitamin C was noticed at zero day and without any impact in all the varieties. Ascorbic acid content ranged from 18.36 to 33.00 mg/100 g fresh weight at zero days. Maximum ascorbic acid was found in Kufri Surya (33.0 mg/100 g fresh weight) followed by Kufri Chipsona-1 (31.46 mg/100 g fresh weight), Kufri Chipsona-3 (26.73 mg/100 g fresh weight), Kufri Frysona (24.80 mg/100 g fresh weight) and Kufri Pukhraj (18.36 mg/100 g fresh weight). The effect from a height of 90 cm resulted in a decrease in ascorbic acid. After 60 days, the decrease was maximum (73.29%) in Kufri Frysona in 90 cm height and minimum (33.22%) in Kufri Chipsona-3 in control (Table 3).

4. Discussion

It has been reported that the amount of moisture is lost through the periderm and can increase up to 60 fold if a tuber is damaged. The results are inconsistent with findings [13] who reported that skinning and cutting of tubers can increase moisture loss from the tubers up to 1000 times that of a non-damaged, well-suberized tuber [14]. It has been reported that any physical damage to tubers increases the water loss and even a small amount of skinning (< 5%), may double the amount of water loss in tubers [15]. Removing the tuber skin, the rate of evaporation increases by 300 to 500 times. The results observed are in agreement with the results reported by [16] who states that avocado fruit becomes more susceptible to bruising impact as the impact height increase.

The quality and appearance of the finished product are of utmost importance to the consumers and industries. Chips of dark or brown color is not at all acceptable. Development of dark chip color was observed as a result in two processing varieties at 60 days after impact. Sugar ends in potatoes in response to stress may develop excess sugars and potatoes when fried at high temperature develop dark-colored chips [17]. Chip color may also be darker due to enzymatic browning or phenolic reaction in damaged tissue [18].

Dry matter of processing varieties should be more than 20% for the development of consistent and crispy texture. Different levels of bruising in early, mature and stored tubers too reported a loss in dry matter [19]. Most of the reports indicate that a close relationship exists between bruising susceptibility and tuber-specific gravity [20]. An explanation for the correlation between bruising and specific gravity agrees that impact damage may be the interaction of starch grains with cell membranes as the cells are full of starch grains and are more vulnerable to susceptibility because starch granules may rupture the membranes during the impact [21]. It has been too reported that dry matter content varies greatly with tuber development, variety and environment [20, 22].

Mechanical shearing may induce tubers to accumulate more sugars. Bruising caused by the artificial simulation may have triggered stress and the potato might have combated the reaction in response. The results are in agreement with the results [23] who states that postharvest factors mechanical stresses and storage conditions are responsible for sugar content in potatoes.

Sucrose content plays an important role during long-term storage. Sucrose was decreased after different impacts. Similar to our study it has been reported that bruising in sugar beet increased sucrose loss. According to one report, 19% of sucrose was lost over a storage period of 4 months following mechanical harvest and handling [24] compared with hand-harvested beet (2% sucrose loss). The decrease in sucrose content and simultaneous increase of glucose in our experiment could be explained by the inversion of sucrose.

The results obtained are in agreement with the findings [25] that physical impact disrupts cellular membranes and the enzyme polyphenol oxidase (PPO) localized within plastids comes into contact with phenolic compounds present in the vacuole and starts a series of reactions that lead to quinones which are bruising pigments. Phenols were higher in variety Kufri Chipsona-1 as compared to Kufri Pukhraj. Enzymatic discoloration occurs due to phenolic compounds when the potatoes are peeled, cut or injured. Variety Kufri Chipsona-1 retains more dry matter and is floury in texture as compared to variety Kufri Pukhraj which is soggy (watery). Because of high dry matter, the impact might have vigorously shattered apart the cells from the pith regions of the variety Kufri Chipsona-1. Oozing of phenolic compounds might have reacted at faster rates in high dry matter variety, resulting in high phenols.

It is believed that free amino acids are an important indicator of the quality of tubers [26]. Free amino acids participation in the Maillard reaction have an ambiguous effect and disturb the relationship between the sugar content and color chips. On frying at higher temperature reducing sugars react with nitrogenous compounds or free amino acids and results in dark color products.

Simulated impact and storage duration reported a decrease in ascorbic acid content. Bruised tomato fruits retain ascorbic acid about 15%-16% lower than in unbruised fruits as reported [27]. According to another study, fruits and vegetables show a gradual decrease in the total ascorbic acid as the storage temperature or duration increases [28]. In one of the studies, potato tubers collected from different locations and their storage up to 30 days reported a decrease in vitamin C content. This could be explained as vitamin C is more sensitive to damage when the commodity is subjected to rough handling and transportation. In addition to that extended time periods of storage and physical damage like bruising decrease vitamin C [29]. Reduction in ascorbic acid content during storage of potato tubers at 10-12 C has too been reported [30].

Varieties behaved differently in response to the impact test. In the variety Kufri Chipsona-1, weight loss with an impact of 30, 60 and 90 cm was reported to be 10.07, 17.32 and 20.14, 13.52, 18.82, 25.31, 14.90, 22.70 and 27.75% at 30, 45 and 60 days of storage respectively. Whereas, in variety Kufri Chipsona-3 it was 14.36, 14.93, 30.5, 15.97, 19.86, 33.06 22.79, 21.32 and 51.31% respectively. After impact from 90cm height, maximum weight loss of 51.31 was reported in variety Kufri Chipsona-3 followed by Kufri Surya 44.31% respectively. The number of cracks was developed more by the variety Kufri Frysona and Kufri Pukhraj. Processing varieties too retained acceptable chip color before 45th day of storage when simulated impact was given. Variety Kufri Chipsona-1 and Kufri Frysona could assemble acceptable reducing sugars up to 45 day did not show acceptable sugar concentration, whereas, variety Kufri Chipsona-3 withstood the impact of 90 cm height impact height and didn't change reducing sugars.

5. Conclusion

It may be concluded from the experiment that the degree of damage increase may vary considerably for different potatoes during postharvest operations. The practice of throwing the fresh potato tubers package from a very high point is not healthy for this crop. The study was conducted to display the fact that increased impact decreases shelf life and nutritional composition of tubers. The data generated may be of great help for end-users and processers in minimizing the mechanical damage. Bruising alters the functioning of plant cells in very important ways. It is quite clear from the results that the quality of potatoes can be affected by physical damage incurred at harvest and handling. Reducing drop heights for this crop may improve potato quality.

Acknowledgements

The authors are grateful to the Director, ICAR-Central Potato Research Institute, Shimla for his encouragement and facilities provided for carrying out the investigation.

Conflict of interest

There is no conflict of interest.

References

[1] Ray RC, Ravi V. Post Harvest spoilage of sweet-potato in tropics and control measures. *Critical Reviews in Food Science and Nutrition.* 2005; 45: 623-644.

[2] Danila DM, Gaceu L. The management of the potato harvesting and handling chain for minimizing the economic losses due to impact loadings. *4th International conference aspects and visions of applied economics and informatics*. Debrecen, Hungary; 2009. p.38-44.

[3] Ferreira MD, Netto LH. Process evaluation on potato packing line. *Horticultura Brasileira*. 2007; 25(2): 279-285.

[4] Singh RB, Kushwaha RK, Verma SK. An economic appraisal of post-harvest losses in vegetable in Uttar Pradesh. *Indian Society of Agricultural Economics.* 2008; 63: 378.

[5] Alexander DP. Bruising of potato 2015; tubers.extensionpublication.unl.edu/assests/pdf/g2271.pdf [Accessed March 4, 2016].

[6] Kumar D, Ezekiel R, Singh B, Ahmed I. Conversion table for specific gravity, dry matter and starch content from under water weight of potatoes grown in North-Indian plains. *Potato Journal.* 2005; 32(1-2): 79-84.

[7] Ezekiel R, Singh B, Kumar D. A reference chart for potato chip colour. *Journal of Indian Potato Association.* 2003; 30(3-4): 259-265.

[8] Nelson N. A photometric adaptation of the Somogyi's method for determination of glucose. *Journal of Biological Chemistry.* 1944; 153(3): 375-380.

[9] Van Handel E. Direct micro-determination of sucrose. *Analytical Biochemistry.* 1968; 22: 280-283.

[10] Sadasivam S, Manickam A. *Biochemical methods*. 2nd ed. New Age International (P) Limited, Publishers, New Delhi; 1996. p.193-194.

[11] Thimmaiah SK. Colorimetric estimation of total free amino acids. *Standard methods of biochemical analysis*. New Delhi: Kalyani Publishers; 2004. p.85-87.

[12] Sadasivam S, Manickam A. Ascorbic acid. *Biochemical methods for agricultural sciences*. 2nd ed. New Age International (P) Limited, Publishers; 1996. p.184-186.

[13] Kleinschmidt G, Thornton M. *Bruise free potatoes: Our goal*. Bulletin No. 725. University of Idaho Cooperative Extension System, Moscow, USA; 1991.

[14] Olsen N, Oberg N. How to keep potatoes in shape-Managing pressure bruise. Potato grower. Post-harvest management of horticultural crops. *Potato Grower.* 2003; 9: 1-2.

[15] Navarre R, Pavek MJ. *The potato: Botany, production and uses*. CABI, Vancouver; 2014.

[16] Baryeh, EA. Strength properties of avocado pear. *Journal of Agricultural Engineering Research.* 2000; 76(4): 389-397.

[17] Asunta LT, Stephen LL, Joseph RS, Michael KT. Review of the sugar end disorder in potato (Solanum Tuberosum L.). *American Journal of Potato Research.* 2008; 85(5): 375-386.

[18] Smith DS, Cash J, Nip W, Hui YH. *Processing vegetables: Science and Technology*. Technomic publishing Co. Inc. Lancaster, Pennsylvania; 1997.

[19] Poberezny J, Goscinna K, Wszelaczynska E, Szczepane M. Influence of mechanical damage and storage on various quality aspects of potatoes. *Journal of Applied Botany and Food Quality*. 2017; 90: 259-265.

[20] Urbany C, Stich B, Schmidt L, Simon L, Berding H, Junghans H, et al. Association genetics in Solanum tuberosum L. provides new insights into potato tuber bruising and enzymatic tissue discoloration. *BMC Genomics.* 2011; 12: 7.

[21] Hughes JC. Potatoes 1: Factors affecting susceptibility to damage. *Span*. 1980; 23: 65-67.

[22] Bandana, Sharma V, Kaushik SK, Singh B, Raigond P. Variation in biochemical parameters in different parts of potato tubers for processing purposes. *Journal of Food Science and Technology.* 2016; 53(4): 2040-2046.

[23] Kumar D, Singh BP, Kumar P. An overview of the factors affecting sugar content of potatoes. *Annals of Applied Biology.* 2004; 145(3): 247-256.

[24] Imura E, Nakayama K, Hayasaka M, Saito H. Relation between mechanical damage and storability in sugar beets. Influence of harvesting equipments on mechanical damage and storability. *Proceedings of the Sugar Beet Research Association.* 1987; 29: 154-160.

[25] Blessington T, Nzaramba MN, Scheuring DC, Hale AL. Cooking methods and storage treatments of potato: Effects

on carotenoids, antioxidant activity and phenolics. *American Journal of Potato Research.* 2010; 87(6): 479-491.

[26] Halford NG, Muttucumaru N, Powers SJ, Gillatt PN, Hartley L, Elmore JS, et al. Concentrations of free amino acids and sugars in nine potato varieties: Effects of storage and relationship with acrylamide formation. *Journal of Agricultural and Food Chemistry.* 2012; 60(48): 12044-12055.

[27] Moretti CL, Sargent SA, Huber D, Calbo AG, Puschmann R. Chemical composition and physical properties of pericarp, locule and placental tissues of tomatoes with internal bruising. *Journal of the American Society for Horticulture Science.* 1998; 123(4): 656-660.

[28] Klimczak I, Malecka M, Szlachta M, Gliszczynska SA. Effect of storage on the content of polyphenols, vitamin C and the antioxidant activity of orange juices. *Journal of Food Composition and Analysis.* 2007; 20: 313-322.

[29] Kuyu CG, Tola YB, Abdi GG. Study on post-harvest quantitative and qualitative losses of potato tubers from two different road access districts of Jimma zone, South West Ethiopia. *Heliyon*. 2019; 5(8): 1-7.

[30] Bandana, Sharma V, Raigond P, Singh B, Kaushik SK. Ascorbic acid losses during storage of potato tubers. *Potato J*. 2015; 42(1): 76-79.