Assessing the Processing Quality of Different Potato Cultivars during Storage at Various Temperatures

[1]Adnan Amjad*, [1]Muhammad Atif Randhawa, [1]Masood Sadiq Butt and [2]Muhammad Asghar
[1]*National Institute Food Science & Technology, University of Agriculture, Faisalabad, Pakistan.*
[2]*Department of Biochemistry, University of Agriculture, Faisalabad, Pakistan.*
adnanft01@gmil.com*

(Received on 13th April 2016, accepted in revised form 28th July 2016)

Summary: Processing industry needs continuous supply of tubers for fries/chips preparation throughout the year. Storage is obligatory to meet the increasing demand of population. Objective of this study was to evaluate the processing and quality characteristics of different potato cultivars (Lady Rosetta, Santé, Hermes, Crozo, Kuroda and Asterix) during storage with 75-80% relative humidity for the period of 160 days at various temperatures (3ºC, 7ºC, 11ºC). Quality parameters such as specific gravity, sprouting, weight loss, dry matter, starch content, ascorbic acid, sugar content and invertase enzyme activity were determined to estimate the processing potential of each cultivar. High Performance Liquid Chromatography (HPLC) equipped with amino (NH_2) column and Refractive Index Detector (RID) was used for the identification and quantification of sugars. The findings of the present work showed that temperature significantly ($p < 0.05$) influenced the processing quality throughout the storage. Low temperature (3ºC) storage caused cold induced sweetening (CIS) due to increased invertase activity whereas, high temperature resulted in sprouting and weight loss of the tubers. Overall processing acceptability for all the cultivars with good frying color was obtained at an intermediate storage temperature of 7ºC in the order of Lady Rosetta > Hermes > Crozo > Santé > Asterix > Kuroda.

Keywords: Cultivars, Storage, Temperature, Processing, Quality.

Introduction

Potato (*Solanum tuberosum* L.) belongs to family *Solanaceae*, a perennial plant herbaceous in nature. The plant grown in Pakistan annually and its propagation carried out through tubers which are thick puffy part of the rhizome found underground [1]. Potato is an essential and balanced food source consists of 20% solid matters and about 80% water with high nutritional significance. Potato is a rich source of starch and vitamins *i.e.* riboflavin, niacin and vitamin C [2]. Moreover, potato is staple diet in European countries and its utilization both in fresh and processed form is rising considerably in Asian countries [3].

Potato is a semi perishable crop usually stored at low temperature to prevent them from sprouting and to ensure regular supply for processing whenever required. Low temperature potato storage is however associated with cold induced sweetening (CIS) which is specifically undesirable in processing potato varieties [4]. CIS occurs due to the imbalance among the rate of starch breakdown and the metabolism of resulting sucrose, a few of which enters in the vacuole where it can be irreversibly cleaved by acid invertase enzyme to the hexose sugars *i.e.* glucose and fructose [5, 6]. Potato tuber undergoes physiological dormancy period during the storage. The length of the dormancy period is dependent on the varietal genetic profile, environmental factors and storage conditions *i.e.* time, temperature and relative humidity etc.

The major part of potatoes consumed by the processing industry is tubers from store. Their suitability relies not only upon the quality of tubers at harvest level but also upon their response to the storage conditions. To enhance potato accessibility throughout the year and to increase the tuber preservation with low/no weight loss and deterioration, proper storage along with controlled temperature conditions are essentially required. The processing characteristics *i.e.* dry matter, starch content, sugar contents, specific gravity, tuber fresh weight and ascorbic acid are need to be balanced during the whole storage period [7]. Contented conditions should preserve tubers in their eatable and saleable situations by inhibiting moisture losses, pathogens spoilage, and sprout growth. By providing cold storage environment, one may reduce weight loss sprouting and spoilage. On the other hand, storage at high temperatures will result in increased respiratory activity and also reduced storage life of potatoes due to weight loss [8].

Currently the most important feature of potato production is tuber's processing quality especially for chips processing this are because consumers are now much more concerned about

*To whom all correspondence should be addressed.

quality, so it is the grower's responsibility to take into account this fact. Potato supply as a raw material for processing industry must fulfill a number of requirements including low sugar contents, high dry matter, more specific gravity, high antioxidants (Vit C), low weight loss, good color and with no sprouting. In Pakistan, the quality and processing characteristics and yield of available potato genotypes are mostly unidentified. It is essential to identify the consumer demands for its various uses and to classify varieties with respect to their behavior during storage at different temperatures [9].

There is a need to develop and evaluate the processing characteristics of different commercial potato cultivars for the benefit of fries/chips industry. The present study has been designed to evaluate the behavior of different potato cultivars upon storage at various temperatures. It will be helpful for the processing industry and growers to get awareness about the most suitable cultivars regarding their processing quality along with the advanced storage conditions. Several potato varieties have been developed and released to the farmers of Pakistan in recent years. Even though these varieties exhibit good tuber characteristics, the comprehensive data regarding their processing and quality characteristics under local ecological and storage conditions need to be evaluated. The present study was such an effort, conducted to take into account the processing quality of different potato cultivars after storage for the preparation of chip/fries.

Experimental

Sample Procurement and Storage

Six potato cultivars (Lady Rosetta, Santé, Hermes, Crozo, Asterix and Kuroda) were procured from the field. Tubers were washed under tap water to remove dust and adhered dirt particles. Washed and cleaned tubers were air dried properly. After drying, all the cultivars were kept in net bags and stored at 3ºC, 7ºC and 11ºC in laboratory scale storage chambers (Memmert, Germany) with 75-80% relative humidity (RH) for 160 days.

Processing and Quality Analysis

Randomly selected medium size potatoes (ten tubers) per each cultivar were taken as represented sample. Samples were taken out in triplicate to conduct the analysis. Initial analysis of all the cultivars at fresh level was conducted before storage and the rest of analysis were performed and compared after 160 days of storage. The following processing parameters were analyzed for chips/fries preparation.

Specific Gravity

Specific gravity is the weight of tuber compared with the weight of the same volume of water. It is a measurement of density and calculated as adopted by Jansky [10].

Dry Matter

For each analysis date, 20 g sample of peeled and thinly sliced (*i.e*. 2 mm) potato obtained from at least three tubers was dried in oven at 110°C for 48 hr. The dry matter content was determined as the dry weight divided by the fresh weight by following the method of Blenkinsop [11].

Ascorbic Acid

Ascorbic acid was determined by titrimetric method using 2, 6 dichlorophenol indophenol dye and results were expressed in mg 100^{-1} g ascorbic acid fresh weight of tubers as determined by Kaur and Aggarwal [12].

Starch

Starch was hydrolyzed into simple sugars by dilute acids and the quantity of simple sugars was measured colorimetrically at 630 nm absorbance as adopted by Kumar [13].

Weight Loss

Tuber fresh weight was taken as initial weight and the weight loss (%) recorded by taking the difference of the weight during storage. At least five tubers were marked up for each variety and their weight was taken by using electronic balance (Shimadzu UX420H, Japan) as illustrated by Elbashir and Saeed [14].

Sprouting

Sprouting of tubers was measured in terms of percentage, by dividing the number of sprouts to the total number of sprouted eyes per tuber [15].

Sample Preparation and Sugar Extraction

Sugar analysis was performed by with some modifications in the methods adopted by Kyriacou [4] and Duarte-Delgado [16]. Three replicate determinations were performed for each sampling

date. A 100 g sample of peeled and chopped potato tuber was obtained for extraction. The sample was mixed and homogenized in 80 mL of methanol for 1.5 min in laboratory scale blender. The homogenate was then added to 5 g activated carbon (150-200 mesh) and shaken well for 20 min at room temperature on a benchtop orbital shaker (IRMICO, OS 10 Instruments, Germany). After that the potato samples were stored for at least 1.5 h at 4°C, followed by vacuum filtration (Rocker, 400 Gottingen Sartorius, Germany). The filtrate was incubated at 35°C for 16 h to precipitate proteins and stored at 4°C before being analyzed by HPLC.

Sample Cleanup and Preparation of Working Standards

Sample cleanup was accomplished by passing the sample through a Sep-Pak Alumina A cartridge (Waters Associates, Milford, MA), followed by filtration through a 0.22 µm nylon filter (Filter-Tek, INC). After filtration, the samples were sonicated prior to inject for at least 15 minutes in ultrasonic water bath at 35ºC to remove air bubbles. Working standard stock solutions of sugars (fructose, glucose and sucrose) were prepared by combining sugars in ultrapure water. The dilutions were carried out to prepare a suitable calibration curve as depicted in Fig. 1. The prepared standard solutions were stored at 4°C.

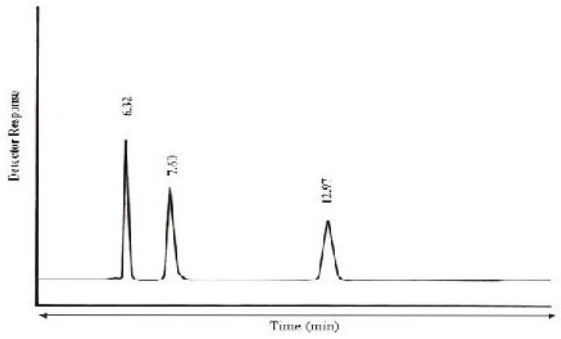

Fig. 1: Standard chromatogram of sugars (left to right fructose, glucose and sucrose).

Chromatographic Analysis

The reducing (fructose, glucose) and non-reducing sugar (sucrose) estimation was done by High Performance Liquid Chromatography (HPLC) equipped with refractive index detector (RID) (Perkin Elmer-series 200) at wavelength of 214 nm using polar bonded phase NH_2 column (25 cm x 4.6 mm id). The mobile phase used was acetonitrile:water (80:20) with flow rate maintained at 1.5 ml min^{-1} and with injection volume of 20µl. Identifications and quantifications of sugars were done by comparing retention times and peak areas of samples to the peak areas of the standards, as peak area was directly proportional to the concentration of the standards throughout the concentration range used. The temperature of column during analysis was maintained at 40°C.

Assay for Enzyme Activity

Acid invertase enzyme was extracted and assayed according to the methods adopted by Bracho and Whitake [17] and Sowokinos [18]. Concentration of protein for the enzyme activity was determined by adopting Bradford method using bovine serum albumin (BSA) as standard and Coomassie brilliant blue G-250 dye as a reagent. Invertase activity was calculated by measuring accumulated reducing sugars formed from the hydrolysis of sucrose. The absorbance was taken at 660 nm by spectrophotometer.

Chips Preparation and Color Evaluation

Tubers were taken out randomly from each replication, hand washed, abrasive peeled and cut longitudinally into uniform 1.5 mm thick slices using an automatic slicer. The slices were washed under tap water to remove surface starch at room temperature and then dewatered by centrifuging at 3000 rpm for 5 min. Slices were dried properly before frying since, drying significantly reduces the oil uptake due to the plasticity and shrinkage acquired by food microstructures [19]. Frying was done in corn oil at fixed temperature (170ºC) for 5 min, in a deep fat fryer till bubbling stopped. The fried slices were removed and excess oil drained off for 1 min, placed on plates, cooled and taken for color evaluation by following the 9-point hedonic scale as adopted by [20]. The samples were coded, sensory analysis for the color was scored by a panel of ten members with different age groups and familiar with fries/chips. The chips color was measured on a scale of 1 to 9 (1 being the darkest and 9 the lightest) under the fluorescent tube light.

Statistical Analysis

Three replicates for each cultivar (five tubers per replicate) were taken for the analysis of fresh and stored tubers at different temperatures. Analysis of variance was performed to screen out the varietal behavior during storage by using the SAS 9.1 statistical package (SAS Institute, Cary, NC, USA) and the analyzed data was presented in means ± standard deviation.

Results and Discussion

Results of the processing and quality parameters after harvesting (fresh) are shown in Table-1. The data indicated that at fresh level higher specific gravity found in Asterix (1.091) following the Lady Rosetta (1.084), Santé (1.082), Kuroda (1.081), Crozo (1.080) and Hermes (1.079). Maximum dry matter at harvest level was also observed in Asterix (24.83%) subsequently Lady Rosetta (23.72%), Hermes (22.85%), Santé (21.08%), Crozo (18.70%) and Kuroda (15.74%). Among all the cultivars, high ascorbic acid content (27.33 mg 100^{-1}g fresh) and starch contents (18.01%) observed in Lady Rosetta. Total sugars in mg 100^{-1} g fresh were investigated in all the cultivars before storage *i.e*. Lady Rosetta (113.17), Santé (152.32), Hermes (122.49), Crozo (139.15), Kuroda (184.44) and Asterix (147.27) respectively.

All the cultivars were subjected to storage at various temperatures for the period of 160 days. The findings of storage at different temperatures for the evaluation of processing quality of each cultivar are illustrated in Tables 1 and 2. It was observed that with the increase in storage days, specific gravity also increased. Maximum increment was recorded at 11ºC for all cultivars as illustrated in Table-1. Specific gravity is one of the most important tools for the quality evaluation and mostly associated with the dry matter or the total solid contents of potato. Specific gravity is an important factor for processors because it affects the quality and yield of the processed product. Increase in specific gravity was associated with the weight loss at higher temperature (11ºC) due to loss of water in tubers during storage and highest specific gravity exhibited by cultivar Asterix (1.098).

Specific gravity of potato tubers influences chips color. It has been reported that tubers having high specific gravity usually produce chips which are light in color [21, 22]. Claassens and Vreugdenhil [23], reported that specific gravity of potato tuber increases during storage due to the rapid depletion of starch reservoirs eventually leading to the overall increase in specific gravity value. Under warm (>10ºC) conditions, increase in specific gravity was also observed by Kaul [24], while storing the processing cultivars at 8 and 11ºC with 90% relative humidity. Our results are in line with the previous studies, the findings of the current study also indicated that higher temperature (11ºC) causes an increase in the specific gravity as compare to low temperature (7ºC and 3ºC). Measurements of specific gravity are often influenced by the known factors such as storage temperature and the differences in the intercellular space of the tuber tissues [13].

Tuber dry matter was directly related to the specific gravity and starch contents. Specific gravity of the tubers, starch and dry matter are proportionally related. The results of dry matter and starch content are illustrated in Tables 1 and 2, respectively. It was found that the dry matter and starch contents increased slightly during the whole storage period. However, Asterix had a maximum dry matter (27.13%) and starch (25.58%) at 11ºC respectively, as high temperature resulted in moisture loss and increase the respiration rate. Dry matter content should be more than 20% for better texture of fries/chips. Tuber dry matter content varies significantly between cultivars and it is a strongly genetic based character. High dry matter content is positively correlated with a lower sugar concentration during storage [25].

Ascorbic acid is naturally present in potatoes. It acts as antioxidant and has nutritional values. Ascorbic acid is also an index of quality change in tubers during storage at different temperatures. Decrease in ascorbic acid content was observed during the whole study in all treatments, however the retention of ascorbic acid was inversely proportional to the higher storage temperature (11ºC). The results regarding ascorbic acid are shown in Table-1, during storage at 3ºC, 7ºC and 11ºC respectively. Ascorbic acid was gradually decreased in all the cultivars, however higher temperature (11ºC) had more influenced in reducing the ascorbic acid (Table-1) as compared to lower temperatures (3ºC and 7º). Maximum reduction of ascorbic acid was found at 11ºC in cultivar Kuroda *i.e*. 13.75 mg 100^{-1}g fresh following the Santé 14.87, Hermes 16.39, Crozo 17.12, Asterix 18.17 and Lady Rosetta 20.34 as depicted in Table-1. After harvest an average level of 20 mg 100^{-1} g fresh weight of ascorbic acid was reported by Brown [3] that may represent up to 13% of the total antioxidant activity of potato tuber. A negative effect on ascorbic acid contents in potato tubers was investigated with an increased intensity of nitrogen fertilization showing that ascorbic acid contents are also based on growing conditions as well as on varietal differences. Decrease in the ascorbic acid occurs during storage however it further reduced during cooking and processing of tubers into chips [26].

The tuber ascorbate content started to decline during storage phase and continue to decrease gradually throughout the whole storage period, depending upon the storage temperature, cultivar susceptibility and type [27]. Loss/elimination of some vital chemical components like ascorbic acid (Vit C) would constitute to loss in overall nutritional value.

Kaur and Aggarwal [12], investigated significant diversity in ascorbic acid content amongst the various potato genotypes. Ascorbic acid content in exotic and Indian potato genotypes ranged 11.80 and 19.42 mg 100^{-1} g fresh weight. Previous studies on various potato genotypes revealed that ascorbic acid content was in the range of 10.60-20.60 mg 100^{-1}g prior to storage but gradually decreased during storage at different temperatures depending upon the cultivar type and storage conditions [28].

Weight loss is generally considered a detrimental factor for fruits and vegetables during storage because it lowers the acceptability of produce to be commercially processed for fries/chips. Weight loss results in dehydration that causes a noticeable skin changes and shrinkage. The results regarding weight loss of potatoes illustrated that cold storage was quite helpful in retaining the fresh weight of the tubers (Table-1). Initially at the start of storage, no weight loss was found but it started gradually after 30 days (data not shown) of storage and it was noticed that higher temperature (11ºC) caused gradual moisture loss during the storage and resulted in weight loss. Lady Rosetta showed the maximum weight loss of 8.2% after storage at higher temperature of (11ºC) following the Asterix 7.41%, Crozo 6.91%, Hermes 6.02%, Santé 5.98% and Kuroda 4.97%, (Table-1). The increase in weight loss above 10ºC storage has also been reported by Kyriacou [4], due to moisture loss and respiration process.

Tuber's sprouting gets started after 4 weeks of storage (data not shown). Sprouting was directly correlated with the tuber weight loss as it increased the tuber respiration rates and ultimately led to low tuber quality. Maximum sprouts were observed in Kuroda (24.67%) stored at 11ºC (Table-1). Hence, low temperature (<10ºC) could be an effective approach in prolonging the dormancy period of tubers. Generally sprouting was not seen in stored potatoes, during the first part of the storage period. However, it usually starts when the dormancy period ends depending upon the storage temperature. Sprout growth is a varietal dependent factor but the temperature has its own role [29], as suggested by Khanal and Uprety [30], that low temperature maintains the storage quality of tubers for longer period as compare to higher temperatures. On the other hand, high amount of dry matter and less sprouting favors longevity of tubers in low temperature storage.

Generally, total sugars were increased during storage due to starch degradation. The results regarding total sugar, reducing and non-reducing sugars are presented in Table-2. The comparative study of sugar accumulation was conducted ($p < 0.05$) for all the cultivars with respect to their storage temperatures (3ºC, 7ºC and 11ºC). The standard chromatogram for all the three sugars (glucose, fructose and sucrose) with their retention times is described in Fig. 1. Significant results ($p < 0.05$) are investigated for all the cultivars during the whole storage period at lower temperature (3ºC) as cold storage caused the more sugar accumulation compare with the high temperatures (7ºC, 11ºC). The results indicated that temperature was negatively correlated with the accumulation of sugars *i.e.* lower the temperature, higher will be the accumulation of sugars. The sugar accumulation observed for all the cultivars was in the order of Kuroda > Santé >Asterix > Crozo > Hermes > Lady Rosetta (Table-2).

Table-1: Specific gravity, dry matter weight loss, sprouting and ascorbic acid content in six potato cultivars, fresh and after storage at various temperatures

Quality parameters	Storage conditions	Potato cultivars					
		Lady Rosetta	Santé	Hermes	Crozo	Kuroda	Asterix
Specific gravity	Fresh	$1.084^{b}\pm0.02$	$1.082^{c}\pm0.01$	$1.079^{de}\pm0.02$	$1.080^{d}\pm0.03$	$1.081^{bc}\pm0.01$	$1.091^{a}\pm0.04$
	3°C	$1.092^{c}\pm0.09$	$1.094^{b}\pm0.06$	$1.086^{e}\pm0.04$	$1.085^{ef}\pm0.07$	$1.088^{d}\pm0.03$	$1.095^{a}\pm0.05$
	7°C	$1.086^{e}\pm0.02$	$1.092^{b}\pm0.04$	$1.085^{ef}\pm0.06$	$1.087^{d}\pm0.03$	$1.089^{c}\pm0.05$	$1.097^{a}\pm0.01$
	11°C	$1.094^{b}\pm0.09$	$1.093^{c}\pm0.05$	$1.087^{f}\pm0.03$	$1.089^{c}\pm0.06$	$1.091^{d}\pm0.07$	$1.098^{a}\pm0.04$
Dry matter (%)	Fresh	$23.72^{b}\pm0.41$	$21.08^{d}\pm0.94$	$22.85^{c}\pm0.99$	$18.70^{e}\pm0.57$	$15.74^{e}\pm0.37$	$24.83^{a}\pm0.58$
	3°C	$24.92^{a}\pm1.41$	$21.96^{d}\pm0.93$	$23.96^{b}\pm1.23$	$19.56^{e}\pm0.72$	$16.62^{f}\pm0.76$	$22.97^{c}\pm0.84$
	7°C	$25.59^{a}\pm1.41$	$22.35^{d}\pm0.60$	$24.01^{bc}\pm1.36$	$20.83^{e}\pm2.09$	$18.53^{f}\pm1.31$	$24.32^{b}\pm1.50$
	11°C	$27.17^{a}\pm2.25$	$24.09^{d}\pm1.01$	$26.88^{c}\pm1.65$	$21.79^{e}\pm2.21$	$19.53^{f}\pm1.61$	$27.13^{ab}\pm2.13$
Weight loss %	Fresh	-	-	-	-	-	-
	3°C	$1.10^{e}\pm0.76$	$1.25^{ab}\pm0.79$	$1.27^{a}\pm0.98$	$1.13^{d}\pm0.81$	$1.13^{d}\pm0.81$	$1.17^{c}\pm0.88$
	7°C	$3.53^{cd}\pm1.64$	$2.73^{f}\pm0.84$	$3.02^{c-e}\pm1.40$	$4.90^{b}\pm1.26$	$3.98^{c}\pm1.38$	$5.97^{a}\pm1.33$
	11°C	$8.20^{a}\pm2.07$	$5.98^{c}\pm1.28$	$6.02^{cd}\pm2.05$	$6.91^{c}\pm1.95$	$4.97^{f}\pm1.98$	$7.41^{b}\pm1.96$
Sprouting (%)	Fresh	-	-	-	-	-	-
	3°C	$4.37^{f}\pm2.53$	$6.23^{e}\pm3.03$	$5.97^{d}\pm2.75$	$7.50^{b}\pm3.76$	$8.30^{a}\pm3.31$	$5.21^{de}\pm1.85$
	7°C	$9.27^{ef}\pm5.37$	$13.67^{bc}\pm4.42$	$12.13^{d}\pm5.29$	$13.73^{b}\pm6.71$	$15.40^{a}\pm4.69$	$10.27^{c}\pm3.15$
	11°C	$18.13^{e}\pm8.04$	$22.61^{b}\pm6.10$	$19.37^{d}\pm6.30$	$20.51^{c}\pm5.57$	$24.67^{a}\pm6.33$	$19.93^{d}\pm5.79$
Ascorbic acid mg 100^{-1}g fresh	Fresh	$27.33^{a}\pm0.95$	$19.03^{f}\pm0.45$	$23.65^{d}\pm0.70$	$25.17^{c}\pm0.46$	$21.90^{e}\pm0.40$	$26.23^{ab}\pm0.50$
	3°C	$22.44^{bc}\pm2.90$	$16.50^{f}\pm2.93$	$20.59^{d}\pm4.22$	$22.93^{b}\pm2.91$	$18.11^{e}\pm2.66$	$23.16^{a}\pm2.88$
	7°C	$24.98^{a}\pm3.76$	$15.48^{ef}\pm2.93$	$18.04^{d}\pm3.12$	$19.34^{c}\pm1.46$	$15.83^{e}\pm1.89$	$21.36^{b}\pm2.24$
	11°C	$20.34^{a}\pm4.87$	$14.87^{c}\pm2.99$	$16.39^{d}\pm2.46$	$17.12^{c}\pm0.90$	$13.75^{f}\pm0.81$	$18.17^{b}\pm1.42$

Values expressed as mean ± standard deviation; means with different letters denote significant differences ($p<0.05$)

Table-2: Starch and sugars in potato cultivars, fresh and after storage at various temperatures.

Quality parameters	Storage conditions	Potato cultivars					
		Lady Rosetta	Santé	Hermes	Crozo	Kuroda	Asterix
Starch %	Fresh	18.01^{a}±2.11	14.41^{cd}±1.64	15.77^{b}±2.38	14.82^{c}±2.47	13.51^{f}±1.79	14.64^{c}±2.48
	3°C	20.12^{b}±0.97	16.99^{ef}±0.67	19.04^{a}±0.77	18.04^{c}±0.42	15.86^{e}±0.60	17.40^{d}±0.42
	7°C	22.27^{a}±1.13	18.05^{d}±1.42	21.39^{b}±1.53	16.04^{f}±1.46	17.08^{e}±1.03	19.93^{c}±1.02
	11°C	23.02^{bc}±1.07	20.11^{e}±1.62	23.51^{b}±1.01	19.36^{f}±0.81	21.07^{d}±0.70	25.58^{a}±0.63
Total sugars mg 100^{-1}g fresh	Fresh	113.17^{f}±6.84	152.32^{b}±6.94	122.49^{e}±9.75	139.15^{d}±4.59	184.44^{a}±5.65	147.27^{c}±6.75
	3°C	265.44^{f}±15.4	355.72^{b}±17.7	273.65^{e}±19.2	285.30^{d}±14.7	385.44^{a}±23.4	330.52^{c}±22.9
	7°C	238.88^{d}±18.7	260.23^{b}±26.9	187.50^{f}±22.9	219.22^{c}±24.3	271.09^{a}±23.1	254.21^{c}±24.1
	11°C	144.73^{f}±21.3	205.57^{b}±20.7	156.73^{e}±19.3	148.32^{d}±18.7	230.72^{a}±23.3	181.16^{c}±17.3
Reducing sugars mg 100^{-1}g fresh	Fresh	58.97^{f}±4.44	78.21^{bc}±5.02	62.47^{e}±7.71	79.88^{b}±3.46	107.04^{a}±4.22	64.07^{d}±4.68
	3°C	191.60^{f}±11.8	262.62^{b}±16.1	209.79^{d}±22.3	207.36^{de}±31.2	289.50^{a}±14.4	245.94^{c}±17.2
	7°C	167.52^{d}±16.3	173.83^{c}±19.7	130.94^{f}±14.1	147.65^{e}±19.3	181.44^{a}±23.9	177.39^{b}±17.3
	11°C	84.82^{e}±13.2	125.19^{b}±21.4	107.64^{d}±23.3	82.50^{ef}±19.7	146.64^{a}±17.1	109.44^{c}±20.7
Non reducing sugars mg 100^{-1}g fresh	Fresh	54.20^{f}±2.40	74.11^{c}±1.92	60.02^{d}±2.04	59.28^{de}±1.13	77.40^{b}±1.43	83.20^{a}±2.07
	3°C	73.83^{d}±10.4	93.10^{b}±14.63	63.87^{e}±9.7	77.94^{d}±11.6	95.94^{a}±14.6	84.57^{c}±13.7
	7°C	66.37^{e}±7.4	86.40^{b}±14.3	56.57^{f}±12.4	71.57^{d}±15.7	89.65^{a}±13.9	76.81^{c}±9.3
	11°C	59.90^{f}±5.34	80.33^{b}±14.3	49.13^{g}±3.86	65.82^{c}±6.8	84.12^{a}±11.7	71.72^{e}±15.6

Values expressed as mean ± standard deviation; means with different letters denote significant differences (p<0.05)

Table-3: Invertase activity[a] in potato cultivars after storage at different temperatures

Potato cultivars	crude protein (mg)[b]	Total activity (units)[c]	Specific activity (units mg^{-1})	crude protein(mg)[b]	Total activity (units)[c]	Specific activity (units mg^{-1})	crude protein (mg)[b]	Total activity (units)[c]	Specific activity (units mg^{-1})
Lady Rosetta	3000	124.11	0.041	2073	72.17	0.034	1481	41.23	0.027
Santé	2461	126.03	0.051	1667	79.79	0.047	1207	44.63	0.036
Hermes	2753	123.24	0.045	2147	87.04	0.040	1332	42.57	0.031
Crozo	2537	122.32	0.048	1714	76.31	0.044	1403	48.56	0.034
Kuroda	2163	127.53	0.059	1821	99.29	0.054	1623	70.31	0.043
Asterix	2311	129.49	0.056	1588	81.37	0.051	1081	42.27	0.039

(p<0.05) [a]based on 1 kg tubers for each cultivar; [b]crude protein; [c]One unit of invertase is the amount of protein that catalyzes the breakdown of 1 µmole of sucrose min^{-1} at 37ºC and pH 4.70.

Low accumulation of sugars (reducing and non-reducing) were observed at 11ºC and the variety Lady Rosetta exhibited the lowest sugars 144.72 mg 100^{-1}g fresh (Table-2) as compare to other cultivars and moderate results noticed at 7ºC temperature. It was observed that low temperature (<10ºC) initiates starch degradation due to the activation of invertase enzyme. Conversely, at higher temperatures, the invertase enzyme responsible for conversion of starch to sugar usually remains inactive resulting in low sugar accumulations. On the other hand, storing tubers at low temperature (<10°C) results in many advantages, such as natural control of sprouting, elimination/reduction of chemical sprout inhibitors and low weight loss during storage [31].

Sugar accumulation in some potato varieties under different storage temperatures (8ºC, 10ºC and 18ºC) were also reported by Kyriacou [4], and maximum sugar contents observed below 10ºC. Uri [15], had determined the sugar, amino acids, organic acid and alcohols of six different potato cultivars grown in Hungary. The storage was conducted at 20-22ºC in darkness. It was observed that storage at this temperature had decreased the fructose and sucrose contents of tubers. The study showed the higher temperature results in low sugar accumulation but sprouting and weight loss of the tubers were increased gradually. There was an inverse relation between sprouting and weight loss compared with the sugar accumulation. Cold storage (<10ºC) requires more energy consumption that also makes it expensive. Whereas, storage at above 10-12°C is low energy consuming and it also prevents undesirable accumulation of reducing sugars [32].

High reducing sugars are negatively corelated with the processing quality of tubers as it results in darkening of the fries and chips upon frying at high temperature. The color of fries is based upon the reducing sugar content of the tubers. Potatoes having high reducing sugar levels make dark fries [33], which is not liked by the consumers. Pandey [34], had also found that the fries color is influenced by reducing sugar content and dry matter of potato. Genetic characters might be a different reason for color variation among genotypes. Abong [7], investigated that different cultivars showed considerable differences in frying color and texture for french fries. Non reducing sugars were calculated by taking the difference of total sugars and reducing sugars. There existed a weak/no relationship between non reducing sugars and the browing fries (Maillard reaction) as reducing sugars were the major reactant between the amino groups of nitrogenous componds resulting in black to brown color upon frying at higer temperature.

Fig. 2: Frying color of potato cultivars after an intermediate storage temperature (7ºC).

Significant results ($p < 0.05$) were obtained among all the cultivars with respect to sugar accumulation and invertase activity. The high ratio of glucose and fructose during storage was due to the increased activity of invertase (Table-3). It was observed that at low temperature the enzyme become active. Invertase is a carbohydrate splitting enzyme; it plays an important role in sucrose hydrolysis to glucose and fructose. Pattern of accumulation of reducing sugars was different among all the cultivars and so the enzyme activity. It has been well documented also by the previous studies that the activity of acid invertase enzyme increases in cold stored tubers [35].

Results revealed that among all the cultivars, highest enzyme activity was observed at storage temperature of 3°C in which the maximum activity shown by cultivar Kuroda 0.059 units mg^{-1} and lowest enzyme activity of 0.041 units/mg observed in cultivar Lady Rosetta (Table-3). The other cultivars exhibited activities of enzyme in units mg^{-1} were Hermes 0.045, Crozo 0.048, Santé 0.051, Asterix 0.056 respectively. Whereas the invertase activity at storage temperatures of 7°C and 11°C was observed *i.e*. Lady Rosetta (0.034, 0.027), Santé (0.047,0.036), Hermes (0.040, 0.031), Crozo (0.044, 0.034), Kuroda (0.054, 0.043) and Asterix (0.051, 0.039) respectively (Table-3). Overall lowest enzyme activity was noticed in tubers stored at 11°C following the storage at 7°C (Table-3). Enzyme unit is the amount of protein required to catalyze the breakdown of 1µmol of the sucrose per minute at 37ºC temperature (pH 4.70).

Significant differences were also by found by Karim [36], in sugar content and activities of carbohydrate splitting enzymes in different tubers of ten indigenous potato cultivars after harvesting and cold storage. The activities of acid invertase, β-galactosidase, cellulose and amylase in all cultivars were found to be increased by 2-12, 1.9-4.5, 1.1-3.7 and 1.2-4 folds, accordingly from harvesting to cold stored potatoes. At low temperature a number of the enzymes responsible for carbohydrate splitting may get activation and play important role for potato sweetening. The rate of invertase activity was the amount of glucose produced during the incubation time at 37ºC. Chips color of all the cultivars was observed after frying at the end of storage as indicated in Fig. 2. The best frying color was noticed among all the cultivars stored at 7ºC as compare to 3ºC and 11ºC e.g. Lady Rosetta (golden yellow), Hermes (slightly yellow), Crozo (yellow), Asterix (yellow brown), Santé (light brown) and Kuroda (dark brown). As frying color was directly associated with the sugar accumulation during prolong storage, therefore color was essential quality criteria for the judgment of the developed product as well as for the satisfaction of consumers.

Conclusion

Overall results evaluated after chips preparation and color assessment showed that cultivars performed well in the order of Lady Rosetta > Hermes > Crozo > Santé > Asterix > Kuroda as presented in Fig. 2. It indicated that an intermediate storage temperature (7°C) had considerably provided superior quality of tubers, since low temperature resulted in cold induced sweetening (CIS) and higher temperature exhibited more sprouting and fresh weight loss ultimately rotting of tubers.

References

1. K. S. Abbasi, T. Masud, M. Gulfraz, S. Ali and M. Imran, Physicochemical, Functional and Processing Attributes of Some Potato Varieties Grown in Pakistan. *Afr. J. Biotech.,* **10,** 19570 (2011).
2. M. Mehdi, T. Saleem, H. K. Rai, M. S. Mir and G. Rai, Effect of Nitrogen and FYM Interaction on Yield and Yield Traits of Potato Genotypes under Ladakh Condition. *Potato Res*., **35**, 126 (2008).

3. C. R. Brown, Antioxidant in Potato. *Am. J. Potato Res.,* **82**, 163 (2005).
4. M. C. Kyriacou, I. M. Ioannides, D. Gerasopoulos and A. S. Siomos, Storage Profile and Processing Potential of Four Potato (*Solanum tuberosum* L.) Cultivars under Three Storage Temperature Regimes. *J. Food Agric. Environ.,* **7**, 31 (2009).
5. J. R. Sowokinos, Biochemical and Molecular Control of Cold Induced Sweetening in Potatoes. *Am. J. Potato Res.,* **78**, 221 (2001).
6. R. W. Blenkinsop, R. Y. Yada and A. G. Marangoni, Metabolic Control of Low-temperature Sweetening in Potato Tubers During Postharvest Storage. *Hort. Rev.,* **30**, 317 (2004).
7. G. O. Abong, M. W. Okoth, J. N. Kabira, J. Ogolla, J. Ouma, C. W. Ngunju and K. Oded, Physico-chemical Changes in Popular Kenyan Processing Potato Varieties as Influenced by Storage Condition. *Cur. Res. Nutr. Food Sci.,* **3**, 112 (2015).
8. M. K. Chourasia and T. K. Goswami, Losses of Potatoes in Cold Storage Types, Mechanism and Influential Factors. *J. Food Sci. Tech.,* **38**, 301 (2001).
9. C. J. Connor, K. J. Fisk, B. J. Smith and L. D. Melton, Fat Uptake in French Fries as Affected by Different Potato Varieties and Processing. *J. Food Sci.,* **66**, 903 (2001).
10. S. H. Jansky, A. Hamernik and P. C. Bethke, Germplasm Release: Tetraploid Clones with Resistance to Cold-Induced Sweetening. *Amr. J. Potato Res.,* **88**, 218 (2011).
11. R. W. Blenkinsop, L. J. Copp, R. Y. Yada, and A. G. Marangoni, Changes in Compositional Parameters of Tubers of Potato (*Solanum tuberosum* L.) During Low-Temperature Storage and Their Relationship to Chip Processing Quality. *J. Agric. Food Chem.,* **50**, 4545 (2002).
12. S. Kaur and P. Aggarwal, Evaluation of Antioxidant Phytochemicals in Different Genotypes of Potato. *Int. J. Eng. Res. App.,* **4**, 167 (2014).
13. D. Kumar, R. Ezekiel, B. Singh and I. Ahmed, Conversion Table for Specific Gravity, Dry Matter and Starch Content from under Water Weight of Potatoes Grown in North Indian Plains. *Potato Res.,* **32**, 79 (2005).
14. H. A. Elbashir and I. K. Saeed, Reconditioning of Cold Stored Potato Varieties (*Solanum tuberosum* L.) Kondor and Markies. *J. Agri Food. App. Sci.,* **2**, 230 (2014).
15. C. Uri, Z. Juhász, Z. Polgár and Z. Bánfalvi, A GC–MS-Based Metabolomics Study on The Tubers of Commercial Potato Cultivars upon Storage. *Food Chem.,* **15**, 159 (2014).
16. D. Duarte-Delgado, C. E. Narváez-Cuenca, L. P. Restrepo-Sánchez, A. Kushalappac, T. Mosquera-Vásqueza, Development and Validation of a Liquid Chromatographic Method to Quantify Sucrose, Glucose and Fructose in Tubers of *Solanum tuberosum* Group Phureja. *J. Chrom. B.*, **975**, 18 (2015).
17. G. E. Bracho and J. R. Whitaker, Purification and Partial Characterization of Potato (*Solanum tuberosum* L.) Invertase and its Endogenous Proteinaceous Inhibitor. *Plant Physiol.,* **92,** 386 (1990).
18. J. R. Sowokinos, C. C. Shocl, T. D. Stieber and E. R. Eldredge, Compositional and Enzymatic Changes Associated with the Sugar-end Defect in Russet Burbank Potatoes. *Am. J. Potato Res.,* **77**, 47 (2000).
19. J. Dehghannya, E. A. Naghavi and B. Ghanbarzadeh, Frying of Potato Strips Pretreated by Ultrasound-Assisted Air-Drying. *J. Food Proc. Pres.* (2015). (doi:10.1111)
20. G. O. Abong, W. O. Michael, K. I. Jasper and N. K. Jackson, Evaluation of Selected Kenyan Potato Cultivars for Processing into Potato Crisps. *Agric. Biol. J. North Am.* **5**, 886 (2010).
21. N. U. Haase, Estimation of Dry Matter and Starch Concentration in Potatoes by Determination of Under-Water Weight and Near Infrared Spectroscopy. *Potato Res.,* **46**, 117 (2003).
22. F. Pedreschi and P. Moyano, Effect of Pre-Drying on Texture and Oil Uptake of Potato Chips. *LWT-Food Sci. Tech.,* **38**, 599 (2005).
23. M. M. J. Claassens and D. Vreugdenhil, Is Dormancy Breaking of Potato Tubers there Reverse of Tuber Initiation? *Potato Res.,* **43**, 347 (2000).
24. A. D. Kaul, P. Kumar, V. Hooda and A. Sonkusare, Biochemical Behaviour of Different Cultivars of Potato Tuber at Different Storage Conditions. NCCI, National Conference on Computational Instrumentation CSIO Chandigarh, INDIA, 19-20 March (2010).
25. W. Amoros, J. Espinoza and M. Bonierbale, Assessment of Variability for Processing Potential in Advanced Potato Populations. CIP Program Report. pp. 185, (2000).
26. K. Hamouz, J. Lachman, P. Dvořák, M. Orsák, K. Hejtmánková and M. Čížek, Effect of Selected Factors on the Content of Ascorbic Acid in Potatoes with Different Tuber Flesh Colour. *Plant Soil. Environ.,* **55**, 281 (2009).
27. M. S. Al-Saikhan, A Simple Diagnostic Technique to Detect Potato Viruses at Post-Harvest Conditions. *Aust. J. Crop Sci.,* **9**, 438 (2015).

28. D. Raj, V. K. Joshi, and B. B. Lal, Yield, Quality and Storability of Potato Flour of Different Indian Cultivars. *Int. J. Food Ferment. Tech.,* **1**, 111 (2011).
29. C. C. Gamboa, E. C. Struik, E. Jacobsen and R. G. E. Vissew, Sprouting of Seed Tubers During Cold Storage and its Influence on Tuber Formation, Flowering and the Duration of the Life Cycle in a Diploid Population of Potato. *Potato Res.,* **46**, 9 (2003).
30. B. Khanal and D. Uprety, Effects of Storage Temperature on Post-harvest of Potato. *Int. J. Res.,* **1,** 214 (2014).
31. R. Pinhero, R. Pazhekattu, A. G. Marangoni, Q. Liu and R. Y. Yada, Alleviation of Low Temperature Sweetening in Potato by Expressing Arabidopsis Pyruvate Decarboxylase Gene and Stress-inducible: A Preliminary Study. *Physiol. Mol. Biol. Plants.,* **17**, 105 (2011).
32. R. Mahto and M. Das, Effect of $^{\gamma}$ Irradiation on the Physico-Mechanical and Chemical Properties of Potato (*Solanum tuberosum* L.), cv. 'Kufri chandramukhi', and 'Kufri jyoti', During Storage at 12°C. *Rad. Phys. Chem.,* **107**, 12 (2015).
33. Anonymous, Commercial Potato Production - Botany of the Potato Plant Western Potato Council*,* Manitoba Agriculture, *Food and Rural Initiatives* (Searched on .2.10). http://www.gov.mb.ca/agriculture/index.html. (2010).
34. S. K. Pandey, S. V. Singh, P. Kumar, D. Kumar and P. Manivel, Sustaining Potato Chipping Industry from Western and Central Uttar Pardesh: Adoption of Suitable Varieties. *Potato J.* **31,** 119 (2004).
35. D. L. Richardson, H. V. Davies, H. A. Ross and G. R. Mackay, Invertase Activity and its Relation to Hexose Accumulation in Potato Tubers. *J. Exp. Bot.,* **41**, 95 (1990).
36. M. R. Karim, M. M. H. Khan, Md. S. Uddin, N. K. Sana, F. Nikkon and Md. H. Rahman, Studies on the Sugar Accumulation and Carbohydrate Splitting Enzyme Levels in Post Harvested and Cold Stored Potatoes. *J. Bio-Sci.,* **16**, 95 (2008).