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Transition in tuber quality attributes of potato (*Solanum tuberosum* L.) under different packaging systems during storage

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Summary

The suitability of different packaging materials i.e. jute, nylon, polypropylene, cotton, low density polyethylene, medium density polyethylene, and high density polyethylene were studied for tubers of the premium potato (*Solanum tuberosum* L.) variety “Lady Rosetta”. After harvest, potato tubers were washed, sorted, graded, cured, and subsequently stored in different packaging materials at ambient temperature (25 ± 2 °C). Changes in quality attributes of potato tubers under different packaging materials were studied on the basis of their physico-chemical and functional parameters. Overall results revealed that packaging materials had a significant ($p \leq 0.05$) effect on many important quality attributes. Generally, weight loss, glucose and glycoalkaloid amounts, and polyphenol oxidase and peroxidase activities increased, while ascorbic acid contents decreased with increasing storage time. Total phenolic contents and radical scavenging activity showed a nearly parabolic trend during the storage period. Amongst the different packaging materials employed, potatoes stored in polypropylene and low-density polyethylene presented the best overall retention of vital quality attributes during 63 days storage. However, the higher tensile strength of polypropylene packaging made it a more durable and thus more effective material for prolonged potato tuber storage, a characteristic having clear advantages when used in typical marketing supply chains.

Introduction

Potato is the most highly produced non-grain staple crop in the world, with one third of total production harvested in densely-populated developing countries, like China and India (PIC, 2008). As such, it is critically important for world food security. Moreover, it is considered the most important crop in South America, the second most important crop in Europe, and fourth on a global scale, after wheat, rice, and maize (MESSER, 2000). One of the greatest challenges to potato tuber production is storage after harvest and greatest quantity of potatoes is lost each year due to inadequate storage conditions after harvest and during marketing. Once the potato tuber is harvested, it is washed and then cured for storage. The curing process leads to the potato tuber entering physiological dormancy (PANDE et al., 2007), and modern commercial potato cultivars grown for the processing industry often have shorter dormancy periods and more susceptibility to storage disorders like sweetening, greening, and others. There is still much work needed to establish appropriate postharvest interventions to ensure optimum tuber storage (quality and duration) to facilitate continuous supply (SUTTLE, 2007). Use of suitable packaging systems extends the storage life of potato tubers during transit, in part by slowing down the ripening process during postharvest storage and marketing (SANCHEZ et al., 2003). In developing countries, the development of effective packaging materials for perishable commodities like potatoes can have tremendous ad-

vantages over more expensive technologies like controlled atmosphere storage facilities, and/or irradiation treatments, as a means to prolonged postharvest storage life. Besides improving food security within country, improved packing strategies that extend commodity shelf life create new options for long-distance shipping of produce to more distant markets.

In many cases today, various packaging systems can be supplemented with low temperature storage (KYRIACOU et al., 2009), sprout inhibitors/suppressants (FRAZIER et al., 2004), ethylene scavengers (ABBASI et al., 2004), and irradiation (BLESSINGTON et al., 2007) as part of an integrated strategy to minimize postharvest losses. The packaging materials themselves are often processed as sheets, wraps, pouches, or more solid containers having diverse barrier properties that modulate gas exchange between the internal and external package atmosphere (HONG et al., 2003). Potato being an important cash crop with substantial export potential could have a major impact on farm incomes and foreign exchange earnings for the exporting country. In developing countries such as Pakistan with a growing potato industry, large bags made of jute (a natural plant fiber, *Corchorus olitorius* L.) with typical carrying capacity of 100 kg are commonly used to store potato tubers after harvest. However, more highly engineered packaging systems that utilize polyethylene, polypropylene, polystyrene, various biodegradable plastics, and wound preventing corrugated cartons and other cushioning materials, are a necessity in many marketing systems to maintain compliance with food safety standards and to compete on the basis of quality in the international market. The quality of horticultural commodities is a critical consideration in decisions made by producers, exporters, and consumers, and the packaging system utilized plays a principle role in determining quality attributes. The present study was designed to identify an optimized packaging system for postharvest storage of the potato variety “Lady Rosetta” at ambient temperature.

Materials and methods

Tubers of potato (*Solanum tuberosum* L.) variety “Lady Rosetta” were harvested from the Potato Research Institute, Sahiwal (Punjab, Pakistan). Tubers were transported the same day to the Postharvest Technology Laboratory, Department of Food Technology PMAS-Arid Agriculture University Rawalpindi, Pakistan. On the same day, the tubers were washed, sorted and graded by size and then cured for one week at temperatures between 15-20 °C before being sampled for analysis here. Potato tubers were packed in different packaging materials (30 cm × 40 cm bags) procured from Ms. Multi Packages Ltd. (Lahore, Pakistan). The set of treatments included control, jute packaging, nylon packaging, polypropylene packaging, cotton packaging, low density polyethylene packaging (LDPE), medium density polyethylene packaging (MDPE) and high density polyethylene packaging (HDPE). One kg of potato tubers were used for each replication, sampling from a total of 30 kg of potato tubers subjected to different physico-chemical assessments each week. All the

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packaged potatoes were stored at approximately 25 ± 2 °C and 70 ± 5 % relative humidity.

Weight loss

The weight loss (%) in different experiments at specified storage intervals was determined by weighing the samples with digital balance (OHAUS, Model TS4KD Florham Park, NJ, USA) and reported as percent loss in sample weight based on initial weight.

Weight loss (%) = (Initial weight - Final weight / Initial weight) × 100

Glucose content

Glucose quantity was determined using glucose test strips imported from Snack Food Association, (Arlington Virginia USA). The color change was correlated with a standard color chart, and the values expressed in mg glucose 100 gm^{-1} sample. The tests were conducted in triplicate per treatment.

Ascorbic acid content

Ascorbic acid (AA) quantity was determined using titrimetric method by employing 2, 6, di-chlorophenol indophenol dye (redox dye) as explained in (AOAC, 1990) method no. 967.21. A 10 g representative sample was placed in a beaker and brought up to volume with 100 ml 3 % phosphoric acid and filtered. 10 ml of filtrate was titrated with the standard dye solution. The ascorbic acid contents (mg 100 g^{-1} dry matter) were quantified as:

Ascorbic acid = (Dye factor × Titration × Volume made up) / (Weight of sample × Volume of filtrate) × 100

Dye standardization

Five milliliters of standard ascorbic acid solution was diluted with five milliliter of metaphosphoric acid (3 %) and titrated with dye solution until a pink coloration could be observed to endure for ten sec. Dye factor was determined (mg ascorbic acid ml^{-1} of dye) as:

Dye factor (D.F) = 0.5 / Titration

Glycoalkaloid content

The total glycoalkaloids (TGA) were determined by the method described by GRUNENFELDER et al. (2006). Ground lyophilized potato tissue (500 mg) was extracted in 10 ml of 80 % ethanol at 85-90 °C for 25 min. The extract were filtered and reduced to 3-5 ml on rotary evaporator at 50 °C. Each extract was rinsed twice with 3 ml of 10 % (v/v) acetic acid and then centrifuged at 10000 g for 30 min at 10 °C. The pH of the supernatants was adjusted at 9.0 with NH_4OH . The extract was refluxed at 70 °C for 25 min followed by overnight storage at 4 °C temperature. The extracts were centrifuged, and after discarding the supernatants the resulting pellets were dissolved in 0.5 ml of 7 % (v/v) phosphoric acid and stored at -20 °C. The Total glycoalkaloids were estimated by adding 200 μl of extract in 1 ml of 0.03 % (w/v) in concentrated phosphoric acid. The contents were allowed to settle for 20 min and absorbance was measured at 600 nm. TGA concentrations were quantified based on α -solanine (Sigma-Aldrich) standard curve using a CE-2021, Spectrophotometer (CECIL Instruments Cambridge, England) and expressed as mg TGA 100 g^{-1} dry weight.

Phenolic content

Total phenolic content (TPC) in terms of gallic acid equivalent (GAE) were carried out by Folin-Ciocalteu (FC) assay (LACHMANN et al., 2008) with few modifications. Tubers randomly selected were

freeze dried and then extracted with 80 % ethanol. A total of 2 gm extract was quantitatively converted into 100 ml volumetric flask and adjusted with 80 % ethanol. In 5 ml of the sample slightly diluted with distilled water, 2.5 ml of FC and 7.5 ml of 20 % solution of sodium carbonate were added. The contents were allowed to settle for 2 hrs and absorbance was measured at 765 nm using a CE-2021, Spectrophotometer (CECIL Instruments Cambridge, England). Total phenolic contents were quantified by standard calibration curve derived from the absorbance of known gallic acid concentration (10-100 ppm). Results were articulated as mg gallic acid equivalents (GAE) 100 g^{-1} dry weight.

Radical scavenging activity (RSA)

Antioxidant activity was measured as radical scavenging activity (RSA) using methods described by SINGH and RAJINI (2004) that involved electron transfer reaction based assay by employing free radical 2, 2-diphenyl-1-picrylhydrazyl (DPPH). Five mg of freeze dried potato extract was incubated with 1.5 ml of DPPH solution (0.1 mM in 95 % ethanol). The reaction mixture was shaken and allowed to stand for 20 min under ambient temperature. Absorbance of the resultant mixture was determined at 517 nm against a blank. The radical scavenging activity was determined as a decrease in the absorbance of DPPH using the following equation:

Scavenging (%) = 1 - (Absorbance of sample at 517 nm / Absorbance of control at 517 nm) × 100

Enzyme determination

Enzyme extraction was carried out by the method described by YEMENICIOGLU (2002), with some modifications. Washed, peeled, and diced potato tubers were placed under -20 °C before homogenate preparation. 200 gm frozen potato tuber was homogenized with 300 ml acetone and 1 gm of polyvinylpyrrolidone (PVPP) in waring blender. The resultant mixture was homogenized for 2 min and then filtered through Whatman No.1 filter paper. Acetone powder preparation was carried out by repeated extraction and evaporation. The extraction mixture was prepared by mixing 0.4 g PVPP, 2 g acetone powder, and 50 ml of cold 8.8 % sodium chloride solution. Extraction was completed at 4 °C temperature 3 hrs under magnetic stirrer. The extract was filtered, centrifuged at 11000 g for 20 min, and then stored at -20 °C prior to quantification of enzyme activity.

Protein extraction was carried out with the LOWRY et al., (1951) method using bovine serum albumin (BSA) as standard. Protein standards of crude and partially purified extracts were prepared in 8.8 % NaCl solution and deionized water respectively. All the assays were carried out in triplicate. The enzyme activity was calculated as U 100 g^{-1} fresh weight, in spectrophotometric assay 1 U was defined as 0.001 change in absorbance $\text{min}^{-1} \text{ ml}^{-1}$ of enzyme extract.

Polyphenol oxidase assay

Polyphenol oxidase (PPO) activity was determined as described by YEMENICIOGLU (2002). The reaction mixture contained 2 ml 0.01 M sodium phosphate buffer (pH 7.0), 0.2 ml of 0.25 M catechol, and 0.3 ml enzyme extract to the total volume of 2.5 ml. The optical density (OD) of the reaction mixture was determined spectrophotometrically at 420 nm. polyphenol oxidase activity was calculated by the change in OD over a period of thirty sec and expressed as U 100 g^{-1} fresh weight.

Peroxidase assay

Peroxidase (POD) estimation was carried out as reported by ABBASI et al. (1998). Reaction mixture consisted of 2.1 ml, 15 mM Na_2KPO_4

buffer (pH 6.0), 0.3 ml 1 mM H₂O₂, 0.3 ml 0.1 mM guaiacol and 0.3 ml enzyme extract to the total volume of 3 ml. The optical density (OD) of the reaction mixture was determined spectrophotometrically at 470 nm. POD activity was estimated by the change in OD due to guaiacol oxidation over thirty sec time and expressed as U 100 g⁻¹ fresh weight.

Statistical analysis

Data obtained as a mean of three replications were statistically analyzed by a two-factor factorial in Completely Randomized Design (CRD) and treatments and storage interval means were compared using a Duncan Multiple Range test using M-Stat-C statistical software as described by STEEL et al. (1997).

Results

Weight loss

Tuber weight loss (%) occurred in all treatments over time; however, the rate of weight loss was slower in packaged tuber than non-packaged controls during the storage period. Treatment means of packaged potato tubers showed non-significant differences between Jute and HDPE, Polypropylene and LDPE, while all other differed significantly. Data on weight loss revealed significant differences between all the storage interval means. The interaction between treatment means and storage intervals showed maximum weight loss (%) in control and minimum in LDPE at the end of storage. In general potato packed in different polyethylene packaging materials (LDPE, MDPE and HDPE) showed lesser weight loss as compared to jute, nylon and cotton packagings (Fig. 1).

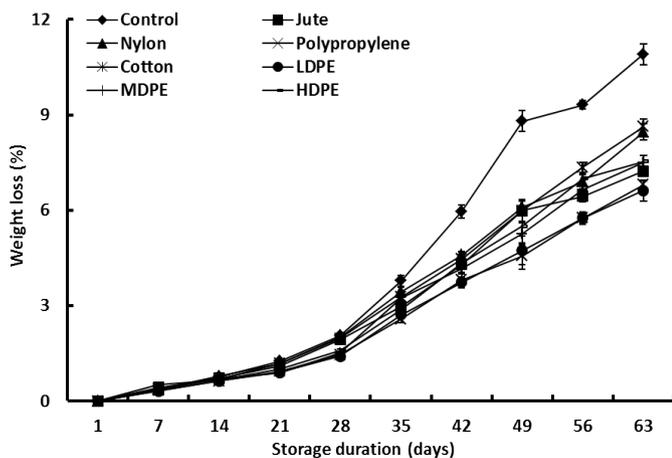


Fig. 1: Weight loss in potato tubers stored using different packaging materials was highest throughout the storage period when stored in polypropylene and LDPE packages. Vertical bars show \pm SE of means (n-3). Interaction between storage intervals and packaging materials was significantly different at $p \leq 0.05$.

Glucose content

Glucose contents showed steady increase throughout the storage period, with an observed impact of applied packaging materials. Treatment means showed significant difference in stored potato with control having maximum while LDPE having minimum glucose over time. Maximum glucose contents were recorded in the last week while minimum during the first week storage. The interaction between storage intervals and treatments was less significant during the early storage, but differed significantly with the progression in the storage period. The prominent increase in glucose contents in the non-packaged control started on the 28th day which gradually in-

creased up to 333.5 mg 100 g⁻¹ (0.333%) by the end of storage. Non-significant differences were recorded between LDPE and MDPE packaging at the end of their respective storage periods, and attained 220 mg 100 g⁻¹ and 215 mg 100 g⁻¹ respectively. The least glucose contents were estimated in polypropylene packaged potato with less than 200 mg 100 g⁻¹ (0.2%) glucose contents throughout the storage period (Fig. 2).

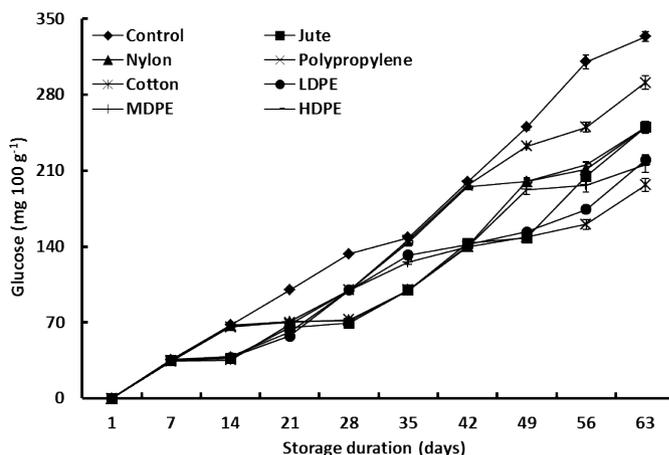


Fig. 2: Glucose content in stored potato tubers stored using different packaging materials was lowest by the end of the storage period when stored in polypropylene packages. Vertical bars show \pm SE of means (n-3). Interaction between storage intervals and packaging materials was significantly different at $p \leq 0.05$.

Ascorbic acid content

In response to different packaging systems, ascorbic acid (AA) was amongst the parameters that decreased significantly during the storage period. Treatment means revealed that the maximum AA retention was observed in LDPE and polypropylene packagings were also found statistically similar at the 5% level of significance. Potatoes packaged in Jute, MDPE and LDPE also maintained higher AA contents than the control. Storage intervals showed significant impact in their AA contents with maximum and minimum values estimated during the first and last weeks, respectively. The interaction between storage intervals and treatments showed substantial AA retention in packaged potato tubers as compared to controls. Amongst different treatments, potato packed in polypropylene packaging and LDPE packaging retained maximum AA contents by the end of storage period. Minimum retention in AA contents was observed in control (15.6 mg 100 g⁻¹) while maximum in polypropylene (19.97 mg 100 g⁻¹) packaging and LDPE (19.2 mg 100 g⁻¹) packaging by the end of storage period (Fig. 3).

Glycoalkaloid content

Total glycoalkaloid (TGA) accumulation in terms of solanine equivalent increased during storage in all the treatments. Treatment means revealed significant difference between the tubers in their TGA contents for the various packaging materials. Maximum and minimum TGA contents during the storage period were identified in Control and HDPE packaging, respectively. Storage interval means showed significant differences in their TGA contents, and these were found to be maximal at the end of the storage period. Results expressed on dry weight basis showed increase in TGA content in potato tubers during storage. However, in all treatments except in control, the TGA levels remained under a safe limit i.e. 20 mg 100 g⁻¹, as suggested by NEMA et al. (2008). In general, irrespective of packaging types, considerable increase in TGA content started on

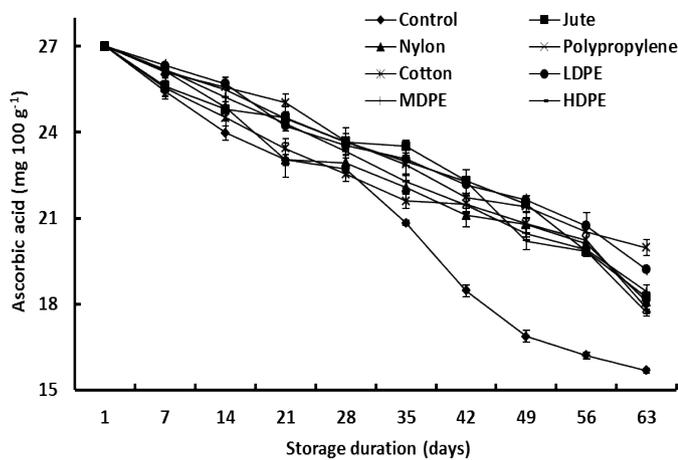


Fig. 3: Ascorbic acid content in potato tubers stored using different packaging materials was highest by the end of the storage period in polypropylene packages. Vertical bars show \pm SE of means (n-3). Interaction between storage intervals and packaging materials was significantly different at $p \leq 0.05$.

the 28th day, which continued till the end of storage. Maximum increase in TGA was about eight folds (7.50 mg 100 g⁻¹ to 63.80 mg 100 g⁻¹) in control at the end of storage as compared to six folds (7.50 mg 100 g⁻¹ to 47.20 mg 100 g⁻¹) increase in tubers in the polypropylene packaging (Fig. 4).

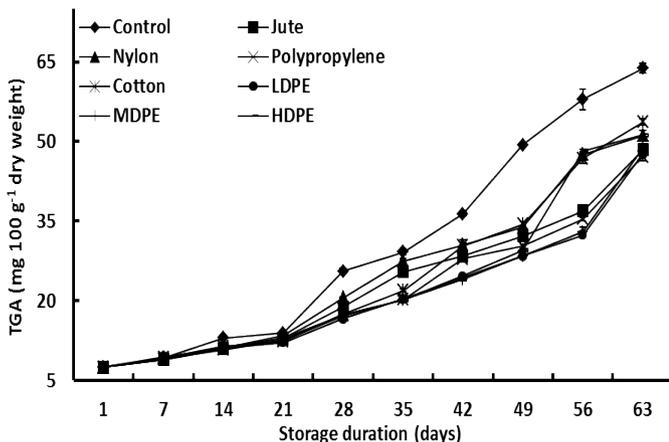


Fig. 4: Total glycoalkaloids (TGA) in potato tubers stored using different packaging materials was highest in non-packaged controls by the end of the storage period. Vertical bars show \pm SE of means (n-3). Interaction between storage intervals and packaging materials was significantly different at $p \leq 0.05$.

Phenolic content

Total phenolic content (TPC) initially showed a trend toward increasing, followed by a decline till the end of storage period. Treatment means showed significant difference in TPC in response to different packagings. Polypropylene and MDPE packagings maintained maximum TPC while control had minimum phenolic content. The interaction between treatments and storage intervals showed maximum TPC in control and polypropylene packaging on 28th and 49th day of storage, respectively. In general, considerable increase in TPC was observed in all treatments up to 42nd day, which subsequently declined by the end of storage. This decline in TPC was more significant in control, nylon, HDPE, and cotton packaged potatoes. After 63rd days storage, potato tubers stored in polypropylene, LDPE, jute, and MDPE packaging retained 137.23 mg GAE 100 g⁻¹, 130.23 mg

GAE 100 g⁻¹, 124.07 mg GAE 100 g⁻¹ and 120.5 mg GAE 100 g⁻¹ TPC, respectively, in contrast to lowest TPC i.e. 88.77 mg GAE 100 g⁻¹ estimated in control (Fig. 5).

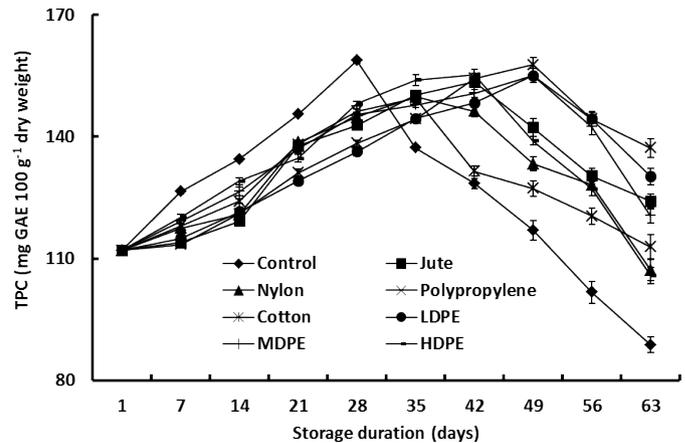


Fig. 5: Total phenolic contents in potato tubers stored using different packaging materials were highest at the end of the storage period when stored in polypropylene packages. Vertical bars show \pm SE of means (n-3). Interaction between storage intervals and packaging materials was significantly different at $p \leq 0.05$.

Radical scavenging activity

Radical scavenging activity (RSA) determined in terms of % inhibition of DPPH showed slight increase initially, followed by a gradual decrease during potato tuber storage. Treatment means showed LDPE packaging maintained maximum activity followed by MDPE, polypropylene and HDPE packaging, while control demonstrated minimum activity. Potato storage in jute, nylon and cotton packaging was found statistically similar, and retained moderate activities throughout the storage period. Radical scavenging activity increased during the first week and attained maximum levels by the second week in all the treatments. In general, maximum RSA activity in tubers occurred between 14-21 days storage, and then progressively decreased after. A considerable reduction in activity was observed in all treatments on the 28th day storage. Potato tubers packed in polypropylene and polyethylene packaging exhibited substantial RSA that retained substantial higher after the fourth week till the end of storage period, with no significant difference between them. The loss in RSA after 14th day till the end of storage in polypropylene was 45.8%-23.8% as compared to 48.0%-17.8% in control (Fig. 6).

Polyphenol oxidase activity

In response to different packaging materials, polyphenol oxidase (PPO) activity in potato tubers generally increased with time. Treatment means demonstrated maximum activity in control, while minimum was recorded in polypropylene and LDPE packaging (statistically similar at 5% level of significance). Moderate PPO activity was observed in jute and HDPE packaging (statistically similar at 5% level of significance). Interaction between storage intervals and treatments was significant with maximum activity estimated in control (68.5 U 100 g⁻¹ fresh weight) at the end of the storage period. In general, steady increase with no significant differences in PPO activity were observed in all the treatments till 28th day, afterward prominent increase was estimated in control till the end. Nevertheless, irrespective of different treatments the PPO activity increased after the fourth week storage. Lowest PPO activity was observed in polypropylene, LDPE and MDPE packaged potato tubers and were found statistically similar during most of the storage period (Fig. 7).

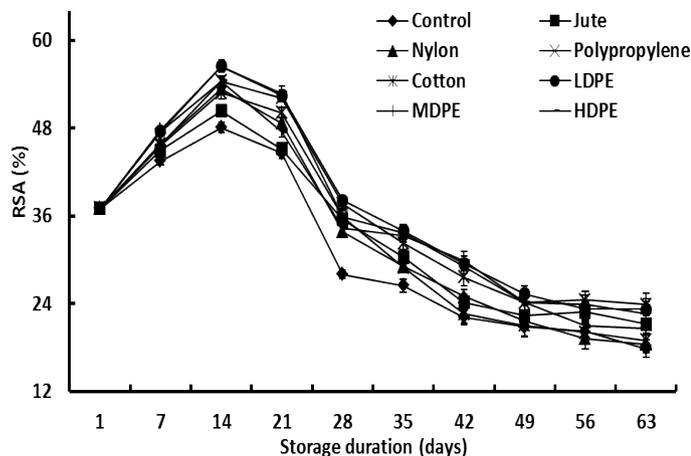


Fig. 6: Radical scavenging activity (RSA) in potato tubers stored using different packaging materials was highest by the end of the storage period when stored in polypropylene. Vertical bars show \pm SE of means (n-3). Interaction between storage intervals and packaging materials was significantly different at $p \leq 0.05$.

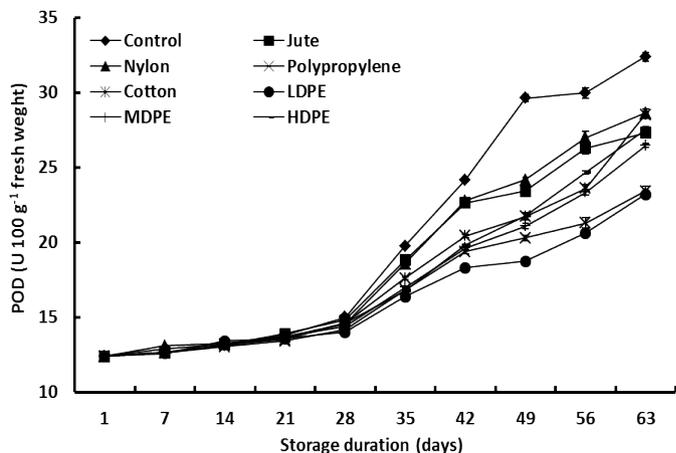


Fig. 8: Peroxidase (POD) in potato tubers stored in different packaging materials was lowest by the end of the storage period when stored in polypropylene and LDPE. Vertical bars show \pm SE of means (n-3). Interaction between storage intervals and packaging materials was significantly different at $p \leq 0.05$.

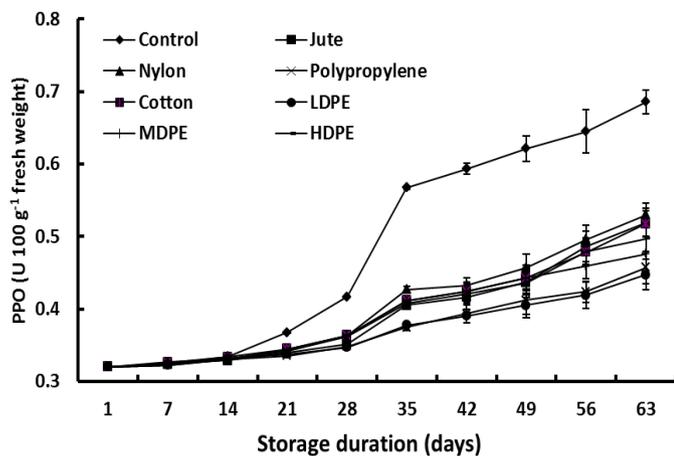


Fig. 7: Polyphenol oxidase (PPO) in potato tuber stored in different packaging materials was lowest by the end of the storage period when stored in polypropylene and LDPE. Vertical bars show \pm SE of means (n-3). Interaction between storage intervals and packaging materials was significantly different at $p \leq 0.05$.

Peroxidase activity

Peroxidase (POD) activity in potato tubers showed a steady increase in all the treatments during storage. However the increase was most prominent in the control. Increased POD activity in potato tuber was comparable to their PPO activity but observed at slower pace. Treatments means revealed maximum POD activity in control and minimum in LDPE packaging during the complete storage. Non-significant difference was observed in jute and nylon packaging, whereas, cotton and HDPE were also found to be statistically similar during their storage period. In general, POD activity was maximum and minimum during the last and first weeks, respectively. Maximum activity POD activity ($32.40 \text{ U } 100 \text{ g}^{-1}$) was estimated in control and minimum ($23.20 \text{ U } 100 \text{ g}^{-1}$) in LDPE packaging at the end of storage. Polypropylene and MDPE packaging retained comparatively lower POD activity i.e. $23.43 \text{ U } 100 \text{ g}^{-1}$ and $26.47 \text{ U } 100 \text{ g}^{-1}$, respectively, during the same storage periods (Fig. 8).

Discussion

As the potato tuber is one of the most important crops supporting worldwide food security, its extended storage life at high quality is

the focus of much interest by growers, exporters, consumers, and researchers. Weight loss by potato tubers during storage results in significant post harvest losses. As an edible plant stem typically forming underground, weight loss is primarily attributed to the water loss that occurs through the outermost skin tissues during the processes of respiration and sprouting (TESTER et al., 2005). The phenomenon is thus considered as an important stability index for the storage life assessment. Packaging systems confer barrier properties to the physiological gaseous exchange of stored tubers and decrease the rate of weight loss during storage (HONG et al., 2003). Different types of packaging material assessed in the present study had a significant impact on potato tuber weight loss during storage. Potato tubers stored in different polyethylene packaging (LDPE, MDPE and HDPE) showed increased percentage weight loss with the increase in the thickness of polyethylene packaging, which might be the reason behind increased weight loss in high density polyethylene packaging as compared to those packed in low density polyethylene. Similar impacts due to thickness and permeability of packaging materials have also been reported by RAKOTONIRAINY et al. (2001). Application of polyethylene packaging in horticultural products like potato tuber (ROSENFELD et al., 1995) and tomato (*Solanum lycopersicum* L.) fruit (SAMMI and MASUD, 2007) have been shown to reduce weight loss during the postharvest storage. Use of polypropylene packaging material has also been shown to effectively prolong storage stability in sweet cherry (CONTE et al., 2009) and fresh cut pineapple (CALDERON et al., 2008).

The hydrolysis of sucrose by the invertase enzyme leads to the formation of glucose and fructose monomers within potato tubers (KUMAR et al., 2004). The presence of either kind of sugars is highly undesirable for tuber processing, as high glucose and fructose are reducing sugars that have a negative effect on potato chip fry color. In addition, high levels of these sugars are a safety concern due to their active participation in toxic acrylamide formation at elevated processing temperatures (MOTTRAM, 2002). The significant increase in glucose contents we report here later in the storage period in treatments like control, jute, nylon, cotton, and HDPE are likely due to earlier sprouting and the associated depletion of carbohydrate reserves in the tuber (BLENKINSOP et al., 2002). By comparison, potato tubers stored in polypropylene, LDPE, and MDPE packaging were observed to delay the dormancy break relative to other materials, and thus retained lower glucose contents at the end of the storage period. The maximum glucose content was reported at the end of storage period for the non-packaged control treatments was associated to

more rapid progress toward dormancy break at the end of the storage period, similar to results of FAUCONNIER et al. (2002).

Ascorbic acid is the predominant vitamin in potato tuber and of significant importance in the human diet. Depletion of ascorbic acid has been implicated with reduced nutritional quality; therefore their assured stability during storage has been a major concern of the post-harvest technologists. HAGG et al. (1998) reported that AA content significantly decreases during storage of potato tuber. The reduction is ascribed to the oxidation of ascorbic acid into dehydro ascorbic acid and afterward to diketogluconic acid. Being a water-soluble vitamin and susceptible to oxidation, AA contents rapidly decrease with increasing rates of respiration and water loss in storage. The present study revealed continuous reduction in AA content in all treatments, but especially then on-packaged controls. Our application of certain packaging materials such as polypropylene and polyethylene could be shown to significantly reduce the rate of water loss from potato, and this was apparently associated with less oxidation of ascorbic acid compared to the controls and other treatments. The efficacy of modified atmosphere packaging in retention of high AA contents has likewise been described in tomato by SAMMI and MASUD, (2007).

Glycoalkaloids contents in potato tuber are attributed to their medicinal and toxicological properties. Low quantities (below 15 mg 100 g⁻¹ fresh weight) impart flavor and functional value, while high quantities (above 20 mg 100 g⁻¹ fresh weight) can impart bitter taste and even may even cause death at excessive intake (28 mg 100 g⁻¹ fresh weight) (MENSINGA et al., 2005). NEMA et al. (2008) reported that total glycoalkaloids (TGA) contents increased during the storage under different packaging systems. He proposed that color, type, and permeability of packaging material effect TGA formation during storage. Similar observations regarding the effect of different packaging materials on TGA contents have been documented by ROSENFELD et al. (1995). In addition, potato tubers produced high level of TGA in the tubers close to sprouting stage, which confirmed the previous findings of SENUGUL et al. (2004).

Large amounts of phenolic compounds can cause tuber discoloration, as phenolics act as a substrate in potato browning mediated through the activities of polyphenol oxidase (PPO) in melanin formation (ANTHON and BARRETT, 2002). However, a high amount of phenolics during storage is attributed to low PPO and high antioxidant activity in potatoes (LACHMAN et al., 2008). Previous studies have revealed that the phenolics content in potato continued to increase during storage period until the onset of PPO activity (MADIWALE et al., 2011). The presence of ample molecular oxygen in control likely caused a significant decline in total phenolics (TPC) as compared to other potatoes stored in different packaging. Our results indicated that packaging materials in general and LDPE and polypropylene packaging in particular curtailed the decline in TPC relative to control, similar as reported by GONZALEZ et al. (2004).

Fruits and vegetables, owing to their rich vitamins and poly phenolic contents, possess significant radical scavenging activity that corresponds to their antioxidant potential (KONDO et al., 2004). These antioxidants have the capacity to quench free radicals (peroxides, super oxides, hydroxyl radicals) thus, protect the cellular structures and proteins from membrane peroxidation and degeneration (DING et al., 2002). In the present investigation, our observation of an initial increase in radical scavenging activity (RSA) might be due to the increase in total phenolic contents observed early in the storage period, as was also reported by (PADDA and PICHA, 2008). Moreover, minimum loss in RSA during the last three weeks of storage and was associated with all packaged potatoes. Potentially, this is due to the regeneration of antioxidant compounds like ascorbic acids in potato to counter balance the increased free radicals produced during senescence. Packaged potato expressed higher antioxidant activity as compare to the non-packaged controls, which might be explained

by greater retention of ascorbic acids, phenolics and other functional compounds. This improved response at later stages of storage in packaging was similar to previous reports of horticultural commodity packaging reported by SONIA and CHAVEZ (2006) and DING et al., (2002).

Polyphenol oxidase activity increases in potato due to the availability of substrate and its subsequent oxidation during storage. The non-significant changes during the 1st month storage in most of the treatments might be due to absence of physical damages and appropriate curing which was also observed by NOURIAN et al. (2003). Prominent increase in the PPO activity in different treatments after the 1st month till the end of the storage period might be associated with an increased substrate (polyphenol) oxidation. However, packaging materials conferred barrier properties to substrate oxidation resulted in low eventual activity as compare to control. In addition, increased PPO activity in potato during postharvest storage has also been implicated with increased sprouting percentage and accelerated senescence (ABBASI et al., 2015). In the present study, all the packaging materials effectively maintained modified atmospheric conditions around potato better than the non-packaged control. This resulted in lower moisture loss and limiting oxygen availability for the polyphenol oxidations. The variation in PPO activity within different packaging materials might be attributed to the difference in their oxygen permeability, which was also observed by RAKOTONIRAINY et al. (2001). KADER (2002) also reported substrate inhibition for PPO enzymes under modified atmosphere packaging, which led to low PPO activity during storage just as we observed in the present investigation.

Enzymatic browning in potato may cause substantial loss by deteriorating nutritional and sensorial attributes, and this is primarily associated with the activities of peroxidase and polyphenol oxidase enzymes during storage (LOAIZA and SALTVEIT, 2001). Peroxidase (POD), being thermally stable and omnipresent in all part of the plant, has a wider range of substrate-based activity than PPO (ANTHON and BARRETT, 2002). Increased POD activity is associated with oxidation of phenolic compounds under physiological stress leading to decay and loss of quality during storage (DING et al., 2002). In addition, POD can also degrade natural antioxidants and liberate damaging free radicals (ROJAS et al., 2008). Both these processes, mediated through peroxidase activity, accelerate potato browning and affect the ultimate postharvest storage life. AYDIN and KADIOGLU (2001) reported increased POD activity in fruits and vegetables under stress conditions, and with progression in the physiological stages from ripening through senescence, just as we observe in the present study as affected by packaging material by the end of storage period. Our results showed that different packaging materials could maintain low POD activity in potato tuber as compare with non-packaged controls at ambient temperature storage, presumably due to lower available oxygen required for the oxidation of phenols and peroxides. The increased POD activity by the end of the storage period, particularly in the non-packaged controls, might be attributed to the physiological stress associated with senescence and sprouting in these tubers, as previously reported by AFIFY et al. (2012) and ABBASI et al. (2015).

Conclusion

This study revealed that storage life in potato tubers was significantly affected by different packaging materials. In general, weight loss, total soluble solids, glucose, total sugars, glycoalkaloids, polyphenol oxidase, and peroxidase increased during the storage period. Ascorbic acids decreased with the increase in storage time. Total phenolic contents and radical scavenging activity of the stored tubers increased initially and then declined later in the storage period. Amongst the different packaging materials studied here, the potato tubers

stored in polypropylene and low density polyethylene packaging showed best overall retention of vital quality attributes during 63rd day's storage. However, tensile strength of polypropylene packaging made it advantageous for prolonged potato tuber storage, which helps prevent potential losses during transit operations and shipping during marketing.

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