
Effects of vacuum packaging on the physical quality of minimally processed potatoes

Ada M. C. N. Rocha, Emilie C. Coulon and Alcina M. M. B. Morais

Escola Superior de Biotecnologia, Universidade Católica Portuguesa, Rua Dr António Bernardino de Almeida, 4200-072 Porto, Portugal

Abstract

Correspondence:

A. M. M. B. Morais,
Universidade Católica
Portuguesa, Rua Dr António
Bernardino de Almeida,
4200-072 Porto, Portugal.
Tel: +351 225 580 050
Fax: +351 225 090 351
E-mail: amorais@esb.ucp.pt

Keywords:

convenience, IV gamma,
minimally processed, potato,
quality, vacuum

In recent years, consumers have become more health conscious in their food choices but they also have less time to prepare healthy meals. As a result, minimally processed (MP) products have become an important sector of the food industry because of their 'fresh-like' qualities, convenience and speed of meal preparation. In this study, the physical qualities of MP potatoes ('Désirée' variety) stored for 7 days in vacuum packaging were evaluated. The shelf life of MP potatoes was effectively extended to nearly 1 week under refrigerated storage by using vacuum packaging systems. The main quality parameters were constant during storage.

Introduction

Potatoes are a crop of ancient origin. They were first cultivated in South America (Andes Mountains) and introduced to Europe in the 16th century. They gained recognition as an inexpensive and nutritious food in the 18th century and are now among the 10 major food crops of the world grown in 140 countries (Macrae & Robinson 1993). They are the most grown vegetable in the world and the fourth most important crop, next to wheat, maize and rice in global tonnage (Macrae & Robinson 1993).

It is well established that the consumption of vegetables is good for health (Krause & Mahan 1985). Potatoes are a good source of carbohydrate, protein, vitamins and minerals. They have a slightly lower energy content (335 kJ per 100 g) than other roots, tubers, cereals and legumes, but this is advantageous in overcoming the problem of obesity in the developed world (Macrae & Robinson 1993). On the other hand, large quantities of potato have been consumed in developing countries to meet their populations' daily energy needs. It has been calculated that 100 g of potato can supply 5–7% of the daily energy and 10–12% of the daily protein needs of children aged 1–5 years (Macrae & Robinson 1993). One hundred grams of potato can supply 3–6% of the daily, human (adult) protein

requirement (depending upon sex and body weight), and one medium-sized potato provides 15 mg of vitamin C, which is about 20% of the recommended allowance (60 mg) per person and per day (RDA 1989).

Consumption of potatoes with the skin increases the dietary fibre intake. It is also a valuable food for those who suffer from excessive acidity of the stomach as it has an alkaline reaction (Macrae & Robinson 1993). Potato fat content is too low to have any nutritional significance, but it does contribute towards palatability. The potato also provides most of the trace elements needed to maintain good health such as iron, potassium, phosphorus, magnesium, sulphur, copper, zinc and manganese which are the most important mineral present. One hundred grams of cooked potato contribute 250 mg of potassium and can supply 6% and 12% of the daily iron requirement for children and adults, respectively (Johnson *et al.* 1968; Macrae & Robinson 1993).

Fruits and vegetables have improved the human diet for centuries, enriching both its nutrition and sensory properties. But as consumers become more health conscious in their food choices, they also have less time to prepare healthy meals. As a result, minimally processed (MP) products have become an important sector of the food industry because of their 'fresh-like' qualities, convenience and speed with which meals can be prepared.

An increasing number of people are consuming at least one meal out of the home. Food service operations often have to prepare large quantities of food, such as potatoes, vegetables, onions and carrots, in a short period of time. Often, they have to prepare (peel and cut) these products the day before consumption which can lead to excessive losses of soluble and sensitive nutrients (Laurila *et al.* 1998). These products, when supplied to the consumer/food service operation in a convenient format, peeled, cored or sliced in prepared packages, with 'fresh-like' qualities and ready for preparation/consumption, comprise in a new category of products called 'Minimally Processed' (MP). Other terms used to refer to MP products are 'lightly processed', 'partially processed', 'fresh processed' and 'pre prepared' (Rocha & Morais 2001).

To be acceptable to consumers/food service operations, MP products must have a 'fresh' appearance, be of consistent quality and be reasonably free of defects. Physical damage or wounding caused by preparation increases the rate of biochemical reactions responsible for changes in colour (including browning), flavour, texture and nutritional quality (such as vitamin loss). The use of vacuum packaging is a promising alternative to chemical treatment, for maintaining the quality of MP vegetables.

Potatoes are extremely sensitive to enzymatic browning. The storage life of peeled or cut raw potatoes is limited by the onset of enzymatic browning at cut surfaces. The discoloration results from the polyphenoloxidase (PPO)-catalized oxidation of phenolic compound to quinone and their subsequent condensation to dark-coloured pigment called melanine (Langdon 1987; O'Beirne & Ballantyne 1987; Sapers & Miller 1992; Chassery & Gormley 1994; Ahevenainen *et al.* 1998; Laurila *et al.* 1998). It is generally assumed that minimal processing operations cause disruption of compartmentalization, allowing substrates and enzymes (oxidases) to come in contact (Brecht 1995). Because it is generally accepted that PPO is the enzyme mainly responsible for browning, an increase in PPO activity after peeling and cutting would be expected (Lattanzio *et al.* 1994).

When the cellular compartmentalization is disrupted, phenolic compounds may be involved in both enzymatic and non-enzymatic browning reactions. In the former case, the oxidation of phenolic substrates is catalysed by PPO activity and the quinones formed can take part in secondary reactions, bringing about the formation of dark secondary products (Laurila *et al.* 1998; Reyes-Moreno *et al.* 2001). In the latter case, the common cause of darkening is attributable to the interactions between phenols and heavy metals, such as iron, which yield coloured complexes (Lattanzio *et al.* 1994). Vamos-Vigyàzò (1981) indicated that the rate

of discoloration following mechanical injury is first higher, then decreases, and finally drops to zero. This conforms with enzyme inactivation and with the pattern of decrease in substrate content observed after bruising (Whitaker 1994; Rocha & Morais 2001).

The origins of controlled/modified atmosphere vacuum food preservation are generally attributed to the research of Kidd and West in the early years of 20th century (Brody 1989). Vacuum packaging, which removes the air from food packages, is now widely used to extend food shelf life and the quality of processed product (Hintlian & Hotchkiss 1986; Brody 1989; Gorris & Peppelenbos 1992; Varoquaux & Nguyen 1994). The use of vacuum packaging greatly inhibits the progress of oxidative reactions and inhibits the growth of aerobic microorganisms, which generally lead to deterioration of foodstuffs during storage (Martens 1995).

A knowledge of the nutritional and physical impacts of minimal processing operations on these products will be an advantage for producers in that they will possess information to create new markets, and for the consumer/food service operation, because they will have a new range of highly convenient products. In this study, the physical quality of MP potatoes ('*Désirée*' variety) stored for 7 days in vacuum packaging was evaluated.

Materials and methods

Plant material

'*Désirée*' potatoes which have a yellow flesh and a purple skin were grown in Portugal. Samples were supplied ready processed and packed by the firm 'Interbatata'. Potatoes were automatically peeled by abrasion, manually selected for visual defects, immediately washed and vacuum-packed. Potatoes were left whole in order for them to be used in a variety of different ways for cooking.

Treatment and storage conditions

Potatoes were packed under vacuum with a Multivac machine (vacuum of 1 mBar during 10 s) and stored in a cold room at 4–6°C. Bags consisted of an outer polyamide (PA) layer and an inner polyethylene (PE) layer with properties in Table 1. The PA gives mechanical strength and impermeability to O₂ and other gases. PE is co-extruded for its water and vapour impermeability (Martens 1995).

Each day of storage a pouch was removed from refrigeration, opened and the potatoes placed in salted water (0.9% NaCl) in order to avoid leaching of sol-

Table 1 Physical properties of packaging film

Package film of 'Desirée'	PA/PE
Film thickness	100 µm
CO ₂ permeability (23°C/50% RH)	145 mL/m ² ·bar·24 h
O ₂ permeability (23°C/50% RH)	35 mL/m ² ·bar·24 h
H ₂ O permeability (23°C/50% RH)	7 g/m ² ·24 h

PA, polyamide; PE, polyethylene; RH, relative humidity.

uble nutrients until used in experiments. Potatoes were evaluated for weight loss, firmness, colour, PPO activity, enzymatic activity, total phenolic compound, titratable acidity, pH, soluble solids content and reducing sugars.

Weight loss

Weight loss was calculated from the weight of five peeled potatoes per replicate measured before and after storage. The weight loss was expressed as a percentage of initial fresh weight. The dry weight was determined by drying a weighed aliquot of potato slices at 85°C for 5 days and re-weighing.

Firmness

Firmness (6 mm deformation) was measured at four different parts of five potatoes (two measurements at the midpoint and two measurements at the top and bottom of the potatoes) with an Instron Universal Testing Instrument (Model 1132, Instron Corp., Canton, OH, USA) for each time of storage. A 100 Newton (N) load cell was used for firmness determination of the potatoes. Cross-head speed was 10 mm/min. This speed was selected considering that potatoes would have to be cooked before eating and therefore what was important is that the chosen speed allowed relative changes of firmness of raw potatoes to be measured. A 7-mm diameter convex tip Magness-Taylor type probe was used. This test measured individual tuber firmness based on the resistance of the potato flesh to deformation by the probe (Kader 1982).

Colour assessment

Cut potato surface colour was measured with a hand-held tristimulus reflectance colorimeter (Model CR-200b, Minolta Corp., Ramsey, NJ, USA). Colour was recorded using the CIE-L*a*b* uniform colour space (CIE-Lab), where L* indicates lightness, a* indicates chromaticity on a green (-) to red (+) axis, and b* chromaticity on a blue (-) to yellow (+) axis. A decrease of L* value and an increase of a* value is a useful indicator of darkening during storage (Mastrocola & Lerici 1991; Monsalve-Gonzalez *et al.* 1993; Rocha & Morais 2001).

PPO activity

Extraction procedure of PPO was described by Rocha & Morais (2001). The potato samples (20 g) were homogenized with 0.2 M pH 6.5 sodium phosphate buffer (extraction buffer) plus 2% polyvinylpyrrolidone (PVPP) for 3 min using a blender jar with external ice bath, with 1 min intervals after each minute of homogenization. The homogenates were centrifuged at 4°C for 30 min at 16000 r.p.m. (Sorvall RC-5C, Instruments Dupont, refrigerated super speed centrifuge). The supernatant was filtered through cheesecloth and its volume determined for enzymatic activity assay.

Enzymatic activity

Enzyme activity was assayed by measuring the rate of increase in absorbance at 420 nm in a Perkin-Elmer Lambda 15 UV/VIS spectrophotometer. The reaction mixture contained 3.0 mL of catechol solution (2.2%), freshly prepared in 0.05 M sodium phosphate buffer at pH 6.5, and a fixed quantity of enzyme. The reference cuvette contained only the substrate solution. The unit for the enzymatic activity was defined as a change of 0.001 in the absorbance value under the conditions of the assay.

Total phenolic compound

Each replicate of potatoes was crushed and filtered through cheesecloth. Total phenolic content was measured using the Folin-Ciocalteu reagent (Folin & Ciocalteu 1927; Singleton & Rossi 1965). Aliquots (0.50 mL) of clear potato juice were diluted in 9.5 mL distilled water, and 4 mL of a diluted Folin-Ciocalteu reagent (1 mL plus 9 mL distilled water) was added to 1 mL of the resulting solution. In the time period between 30 s after the addition of Folin-Ciocalteu reagent, but before 8 min elapsed, 4 mL of sodium carbonate solution was added. After 1 h at 30°C plus 1 h at 0°C, the absorbance of the solution was measured at 760 nm. Dopamine was used to obtain the standard curve (0.5–5.0 µg dopamine/mL), and the concentration of phenols was calculated directly from that curve, because the standard and samples were treated identically. Total phenols were expressed as µg dopamine/100 g of potato fresh weight.

Titratable acidity and pH

Aliquots (10 mL) of potato juice were diluted with 40 mL of distilled water and titrated with 0.1 N NaOH, beyond pH = 8.2. This potentiometric titration was performed with a pH meter Crison, Model Micro pH 2002 (Crison Instrument, S.A., Barcelona, Spain). The results were calculated as a percentage of malic acid [(ml NaOH*0.1 N/mL sample titrated)*100].

The pH was measured in the juice of the crushed potato before pH determination, using a pH meter Crison, Model Micro pH 2002 (Crison Instrument) which had been previously standardized to pH 4 and pH 7, and a xerolyt electrode Ingold Lot 406-MG-DXK-57/25.

Soluble solids content

The soluble solids content of non-diluted juice from crushed potatoes was determined at 20°C (room temperature) with a hand refractometer, Model Atago – ATC1. Results were expressed in °BRIX (1° BRIX = 1 g soluble solid/100 g solution).

Reducing sugars

Each replicate of potatoes was crushed and filtered through a cheesecloth. Reducing sugar was measured using the dinitrosalicylic (DNS) reagent. First, aliquots (1 mL) of clear potato juice were diluted in 49 mL distilled water. About 900 µL of this solution was pipetted into a test tube, followed by addition of 100 µL of NaOH 0.1 M and 1 mL of DNS reagent. Then, the test tubes were placed in a boiling water bath (120°C) for 5 min, and 4 mL of distilled water was added. The absorbance of the solution was measured at 540 nm. Glucose was used to obtain the standard curve (0.1–0.6 g/L), and the concentration of reducing sugar was calculated directly from that curve, because the standard and samples were treated identically. Reducing sugars were expressed as g sugars/100 g of potato fresh weight.

Control

Two controls were performed by storing vacuum-packed potatoes at room temperature and also by storing peeled potatoes packed in perforated bags under refrigeration (6°C).

Results and discussion

Weight loss and firmness

'Desirée' potato dry weight was 22%. The weight loss after 7 days of storage was about 3% (Fig. 1) which is considered quite low.

This probably results from the vacuum package: moist food did not dry out because there is no air to absorb the moisture from the food. Nevertheless, we noticed an unexpected decrease in weight loss for 'Desirée' potato at the end of the storage. This decrease was unexpected because it occurred in the last days of

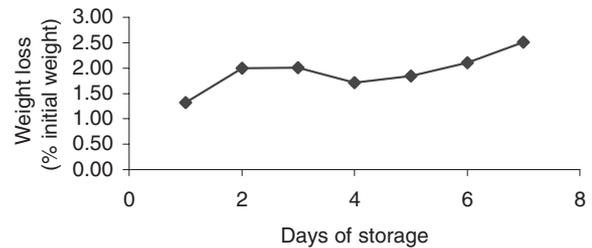


Figure 1 Weight loss (%) of vacuum-packed 'Desirée' potato during storage at 6°C in the dark.

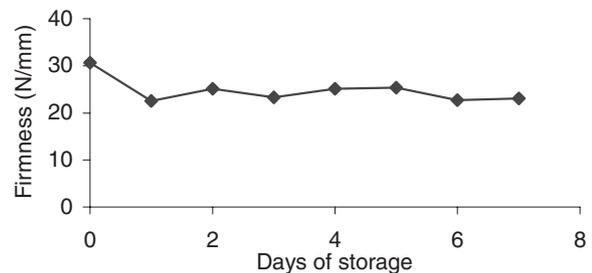


Figure 2 Firmness (N/m) of vacuum-packed 'Desirée' potato during storage at 6°C in the dark.

storage and it was not followed up by any change in firmness (Fig. 2).

Many researchers have indicated that the fundamental problem in the extension of shelf life of MP fruits and vegetables is the loss of firmness during storage and distribution. This results from the action of endogenous enzymes on the cell wall and growth of microorganisms (Rocha & Morais 2001). A 25% loss of firmness of 'Desirée' potatoes was observed after the first day, probably showing an increased enzymatic activity immediately after mechanical damage caused by processing operations. After that, firmness of 'Desirée' potatoes was constant during the remaining days of storage (Fig. 2).

According to Shetty *et al.* (1989), potato plastic wraps that decreased weight loss also tended to maintain tuber firmness. Firmness relates to turgidity of the potato and it is best maintained when water loss is reduced. The retention of firmness during vacuum storage of 'Desirée' potatoes must be related to the ability of the film used to decrease moisture loss and thereby maintain the integrity of the internal tuber tissue, including membranes. It should be also noted that the retention of firmness in the potatoes during the storage period is a further indication of the absence of significant microbial spoilage of the product (Chassery & Gormley 1994).

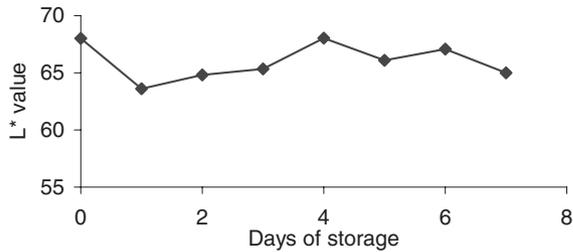


Figure 3 L* value of vacuum-packed 'Desirée' potato during storage at 6°C in the dark. L* indicates lightness.

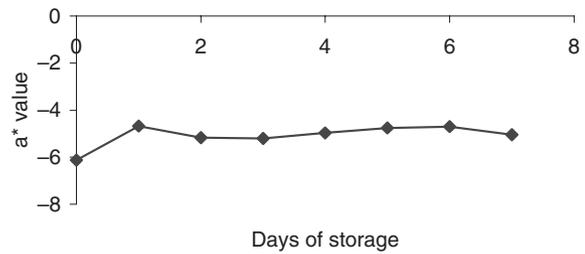


Figure 4 a* value of vacuum-packed 'Desirée' potato during storage at 6°C in the dark. a* indicates chromaticity on a green to red axis.

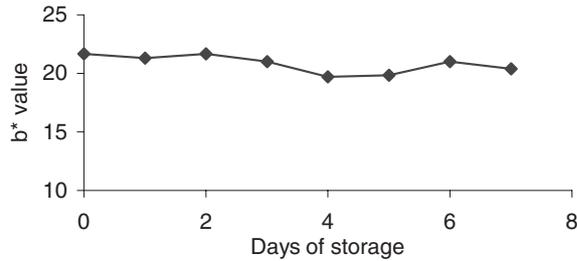


Figure 5 b* value of vacuum-packed 'Desirée' potato during storage at 6°C in the dark. b* indicates chromaticity on a blue to yellow axis.

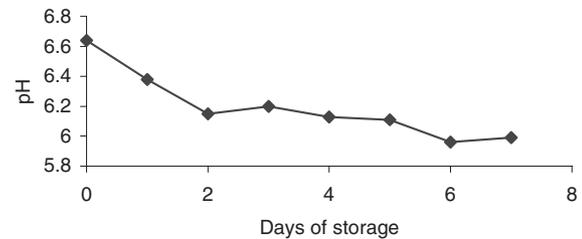


Figure 6 pH value of vacuum-packed 'Desirée' potato during storage at 6°C in the dark.

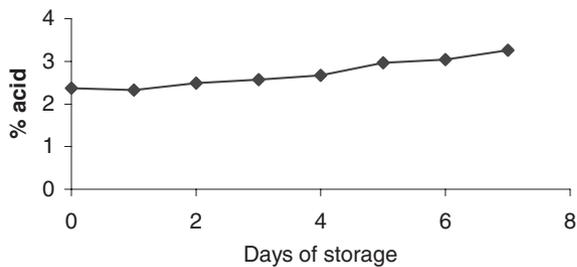


Figure 7 Acidity of vacuum-packed 'Desirée' potato during storage at 6°C in the dark.

Colour assessment

Oxidative browning of the surface of MP fruits and vegetables surface has been extensively reported. Most of the time it has been considered the limiting factor of shelf life of MP products (Carlin *et al.* 1990; El-Shimi 1993; Kim *et al.* 1993; Brecht 1995; Rocha & Morais 2001). Colour changes of vacuum-packed 'Desirée' potatoes were not significant. A small decrease of lightness (L* value) was observed (Fig. 3). There is no significant change in a* and b* values during the storage (Figs 4 and 5).

Titrateable acidity and pH

A decrease in pH value of 'Desirée' potatoes was observed, which was obviously correlated to the

increase observed in acidity (Figs 6 and 7), nevertheless those changes were not significant. This is desirable from the sensory point of view, because a variation in pH value would most certainly imply a negative change in flavour (Huxsoll & Bolin 1989).

Reducing sugars and soluble solids

The sugar content of potatoes may vary from only trace amounts to as much as 10% of the dry weight of the tuber (Burton 1989). Sucrose, glucose and fructose are the main sugar compounds. Other sugars have been detected in potatoes but only in trace amounts. Many other plant tissues including potatoes often undergo a phenomenon known as low temperature sweetening after exposure to low temperatures (Coffin *et al.* 1987). Nevertheless, no changes were observed in the reducing sugar content of 'Desirée' potatoes after 7 days of storage. Small variations were noticed during storage with an increase on the first day of storage followed by a decrease at the third day (Fig. 8).

The initial increase might be related to the breakdown of high molecular weight compounds such as starch and hemicellulose into low molecular weight compounds such as simple sugars (Coseteng & Lee 1987; Shetty *et al.* 1989). The following decrease from days 1–3 might be the result of sugar consumption as a substrate in metabolic processes (Ackermann *et al.* 1992), which might have overcome the first effect. Nev-

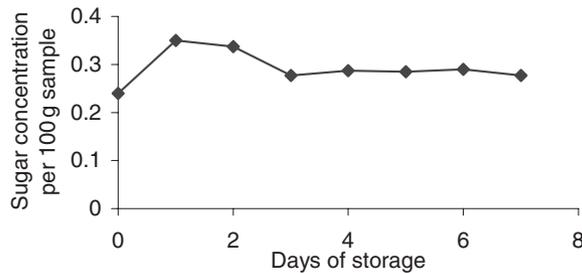


Figure 8 Reducing sugars of vacuum-packed 'Desirée' potatoes during storage at 6°C in the dark.

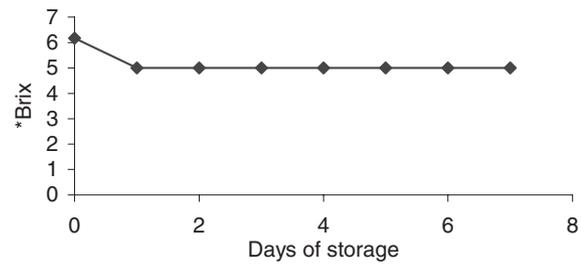


Figure 9 Soluble solids of vacuum-packed 'Desirée' potato during storage at 6°C in the dark.

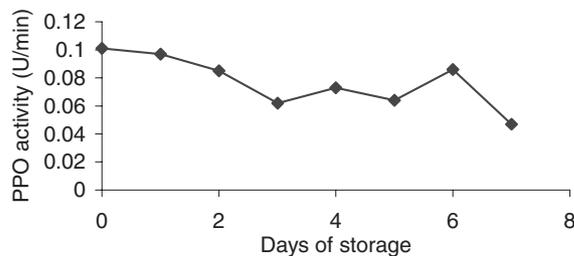


Figure 10 Polyphenoloxidase (PPO) activity of vacuum-packed 'Desirée' potato during storage at 6°C in the dark.

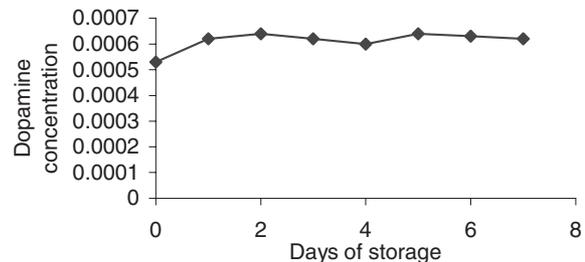


Figure 11 Total phenolic compound of vacuum-packed 'Desirée' potatoes during storage at 6°C in the dark.

ertheless, those changes were not reflected in the soluble solids content: no significant changes were observed (Fig. 9).

PPO activity

PPO activity of 'Desirée' potatoes presented a small decrease during storage time (Fig. 10). Those results were in accordance with the colour assessment. Indeed, we noticed a small decrease of the L^* value which should be related to the development of browning. Heimdal *et al.* (1995) showed that enzymatic browning of lettuce by PPO was inhibited by moderate vacuum packaging in 80 μm PE bags during about 3 weeks.

Phenolic content

The total phenolic compound of 'Desirée' potato was 0.6 μg dopamine/100 g of potato fresh weight. A small increase of total phenolic content for 'Desirée' potato was observed in the first day of storage immediately after minimal processing operations (Fig. 11).

Buescher *et al.* (1974) also reported that the phenolic content of snap beans pods increased after being broken. Ke & Saltveit (1989) reported that wounding, by cutting the leaves or puncturing the tissue of iceberg lettuce, caused an increase of total soluble phenolic content, but those compounds were oxidized into brown substances in minutes by PPO. Howard & Grif-

fin (1993) reported an increase in total phenols of MP carrot sticks and associated this with a wound-induced increase in PAL (phenylalanine-amonia-lyase). Lattanzio *et al.* (1994) found that the phenolic content of artichoke heads was generally higher in mechanically damaged samples than in intact ones, although they had expected a reduction of phenolic content because of oxidative phenomena.

Control

The vacuum-packed potatoes stored at room temperature became brown after 2 days and after 4 days they had deteriorated to the point they were inedible.

The peeled potatoes stored under refrigeration became brown since the first day of storage and after 4 days were completely inedible.

As can be seen, the keeping quality of vacuum-packed potatoes is extremely high and presents a number of obvious advantages to food service operations. This product is 'fresh-like' and presents high convenience and speed with which meals can be prepared. This is also very appealing to the consumer.

Conclusion

Vacuum packaging appeared to be an effective package for protection of the quality of MP 'Desirée' potatoes. The shelf life of MP potatoes may be extended to

1 week under refrigerated storage by using vacuum packaging systems.

The main quality parameters are constant during the storage. The 'fresh-like' quality of potatoes was effectively preserved by a 100- μm PE/PA bag, an outer PA layer and an inner PE layer. The PA is responsible for mechanical strength and impermeability to O_2 and other gases. PE is co-extruded for its water and vapour impermeability. PPO activity was greatly inhibited by vacuum packaging using 100 μm PE bags.

Because the absence of air in vacuum packaging may favour the growth of anaerobic pathogens, such as *Clostridium botulinum*, it would be of extremely importance to develop the microbiological evaluation.

Acknowledgements

The authors acknowledge the firm Interbatata from Lourinhã, Portugal for the supply of the potatoes and information about the processing conditions and the crop.

References

- Ackermann J, Fischer M, Amado R (1992). Changes in sugars, acids, and amino acids during ripening and storage of apples (Cv. Glockenapfel). *Journal of Agricultural and Food Chemistry* 40:1131–4.
- Ahevenainen RT, Hurme EU, Hagg M, Skytta EH, Laurila EK (1998). Shelf life of prepeeled potato cultivated, stored, and processed by various methods. *Journal of Food Protection* 61:591–600.
- Brecht JK (1995). Physiology of lightly processed fruits and vegetables. *Hortscience* 30:18–21.
- Brody A (1989). Introduction. In: *Controlled/modified Atmosphere/vacuum Packaging of Foods* (ed. A Brody), pp. 1–16. Food and Nutrition Press, Inc.: Trumbull, CT.
- Buescher RW, Reitmeier C, Sistrunk WA (1974). Association of phenylalanine ammonia lyase, catecholase, peroxidase and total phenolic content with brown-end discoloration of snap bean pods. *Hortscience* 9:585.
- Burton WG (1989). The distribution and composition of the dry matter in the potato tuber. In: *The Potato* (ed. PM Harris), 3rd edn, p. 286. Longman: Harlow.
- Carlin F, Nguyen-The C, Varoquaux P (1990). La conservation des produits de la 4ème gamme. *Actualites des Industries Alimentaires et Agro-Alimentaires* 10:931–44.
- Chassery S, Gormley TR (1994). Quality and shelf life of prepeeled vacuum packed potatoes. *Farm & Food* July/December:30–2.
- Coffin RH, Yada RY, Parkin KL, Grodzinski B, Stanley DW (1987). Effect of low temperature storage on sugar concentrations and chip color of certain processing potato cultivars and selections. *Journal of Food Science* 52:639–45.
- Coseteng MY, Lee CY (1987). Changes in apple polyphenoloxidase and polyphenol concentration in relation to degree of browning. *Journal of Food Science* 52:985–9.
- El-Shimi N (1993). Control of enzymatic browning in apple slices by using ascorbic acid under different conditions. *Plant and Foods for Human Nutrition* 43:71–6.
- Folin D, Ciocalteu V (1927). On tyrosine and tryptophane determinations in proteins. *Journal of Biology and Chemistry* 73:627–50.
- Gorris LGM, Peppelenbos HW (1992). Modified atmosphere and vacuum packaging to extend the shelf life of respiring food products. *Horttechnology* 2:303–9.
- Heimdal H, Kuhn BF, Poli L, Larsen LM (1995). Biochemical changes and sensory quality of shredded and MA-packaged Iceberg lettuce. *Journal of Food Science* 60:1265–8, 1276.
- Hintlian CB, Hotchkiss JH (1986). The safety of modified atmosphere packaging: a review. *Food Technology* 12:70–6.
- Howard LR, Griffin LE (1993). Lignin formation and surface discoloration of MP carrot sticks. *Journal of Food Science* 58:1065–7.
- Huxsoll CC, Bolin HR (1989). Processing and distribution alternatives for MP fruits and vegetables. *Food Technology* 2:124–8.
- Johnson FB, Hoffman I, Petrasovits A (1968). Distribution of mineral constituent and dry matter in the potato tuber. *American Potato Journal* 45:287–9.
- Kader AA (1982). Proper units for firmness and abscission force data. *Hortscience* 17:707.
- Ke D, Saltveit ME (1989). Wound induced ethylene production phenolic metabolism and susceptibility to russet spotting in iceberg lettuce. *Physiology Plant* 76:412–18.
- Kim DM, Smith NL, Lee CY (1993). Quality of MP apple from selected cultivars. *Journal of Food Science* 58:1115–17.
- Krause MV, Mahan LK (1985). Dietetic necessities recommended and adequate diet. In: *Food, Nutrition and Diet Therapy* (eds MA Krause & LK Mahan), pp. 215–46. W.B. Saunders Company: New York.
- Langdon TT (1987). Prevention of browning in prepared potatoes without the use of sulfiting agents. *Food Technology* 41:64–7.
- Lattanzio V, Cardinali A, Palmieri S (1994). The role of phenolics in the postharvest physiology of fruits and vegetable: browning reaction and fungal diseases. *Italian Journal of Food Science* 1:3–22.
- Laurila EK, Hurme EU, Ahvenainen RJ (1998). Shelf life of sliced raw potatoes of various cultivar varieties. *Journal of Food Protection* 61:1363–71.
- Macrae R, Robinson RK (1993). Potatoes and related crops. In: *Encyclopaedia of Food Science, Food Technology and Nutrition* (eds R Macrae, RK Robinson & MJ Sadler), pp. 3672–86. Academic Press Inc: San Diego, CA.
- Martens T (1995). Current status of sous vide in Europe. In: *Principles of Modified-Atmosphere and Sous Vide Product Packaging* (eds JM Farber & KL Dods), pp. 37–68. Technomic Publishing Inc: Lancaster.
- Mastrocola D, Leric CR (1991). Colorimetric measurements of enzymatic and non-enzymatic browning in apple purees. *Italian Journal of Food Science* 3:219–29.
- Monsalve-Gonzalez A, Barbosa-Cánovas GV, Cavalieri RP, McEvily AJ, Iyengar R (1993). Control of browning during storage of apple slices preserved by combined methods. 4-Hexylresorcinol as antibrowning agent. *Journal of Food Science* 58:826.
- O'Beirne D, Ballantyne A (1987). Some effects of modified atmosphere packaging and vacuum packaging in combination with antioxidants on quality and storage life of chilled

- potato strips. *International Journal of Food Science and Technology* 22:512–23.
- RDA (1989). *Recommended Dietary Allowances*. Subcommittee on the tenth edition of the RDAs. Food and Nutrition Board. Commission on Life Sciences. National Research Council. National Academy Press: Washington, DC.
- Reyes-Moreno C, Parra-Inzunza MA, Milan-Carrillo J, Zazueta-Niebla JA (2001). A response to surface methodology approach to optimise pretreatments to prevent enzymatic browning in potato (*Solanum tuberosum* L) cubes. *Journal of the Science of Food and Agriculture* 82:69.
- Rocha AMCN, Morais AMB (2001). Characterization of PPO extracted from 'Jonagored' apple. *Food Control* 12:85–90.
- Sapers GM, Miller RL (1992). Enzymatic browning control in potato with ascorbic acid-2-phosphate. *Journal of Food Science* 57:1132–5.
- Shetty KK, Kochan WJ, Dwelle RB (1989). Use of heat-shrinkable plastic film to extend shelf life of 'Russet Burbank' potatoes. *Hortscience* 24:643–6.
- Singleton AD, Rossi JA Jr (1965). Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal of Enology and Viticulture* 16:144–58.
- Vamos-Vigyàzò L (1981). Polyphenoloxidase and peroxidase in fruits and vegetables. *Critical Reviews in Food Science and Nutrition* 9:49–127.
- Varoquaux PJA, Nguyen-The C (1994). Vacuum processing: a new concept for pre-cooked fruit and vegetables. *Proceedings. Food Science and Technology Today* 8:42–9.
- Whitaker JR (1994). Effect of substrate concentration on rates of enzyme-catalysed reactions. In: *Principles of Enzymology*, pp. 167–99. Marcel Decker Inc.: New York.