PT220
Non frozen fresh potato products

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Food Science Australia

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PT220
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CONFIDENTIAL PROJECT REPORT

NON FROZEN FRESH POTATO PRODUCTS

Report for: **Horticultural Research & Development Corporation**

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7 January 1998

INDUSTRY SUMMARY

Consumers desire for convenience and freshness has created emerging market for new products such as pre-prepared washed, peeled and/or sliced potatoes. At present, fresh potato products at the domestic market rely heavily on the use of sulphur dioxide and vacuum packaging which gives a very short shelf life. This project was conducted in order to develop and evaluate the effectiveness of an integrated processing, packaging, and controlled storage and handling as an alternative to freezing and/or the use of sulphur dioxide in extending the shelf-life of fresh peeled potato products.

This project was able to develop and evaluate an integrated system for extending the shelf-life of pre-peeled potatoes without the use of sulphur dioxide under commercial processing conditions. The developed novel system was proven to maintain the quality and safety of pre-peeled potatoes up to 2 to 4 weeks under refrigerated conditions.

The newly developed preservation integrates the following technologies: (i) edible polysaccharide coating, (ii) anti-browning agents, (iii) modified atmosphere packaging, and (iv) low temperature storage. Shelf-life trials using knife-peeled, and commercially steam-peeled and abrasive-peeled potatoes showed inhibition of both enzymatic browning and microbial growth of up to 3 weeks at 4°C and up to 4 weeks at 1°C. Current shelf-life of peeled potatoes treated with sodium metabisulphite and packaged under vacuum is about a week.

Further tests conducted using various cultivars were able to confirm the effectiveness of the newly developed preservation system. Potato cultivars used in this study included *Sebago, Coliban, Russet Burbank, Desiree, Nicola, Spunta, Kipfler, Toolangi Delight, Patrones*, and *Denali*. All cultivars showed an acceptable shelf-life of 2 to 3 weeks at 4°C, hence demonstrated the effectiveness of the new preservation system.

Food Science Australia has successfully applied for the variation of Australia and New Zealand Food Authority (ANZFA) Food Standards Code to permit the use of edible coatings and associated anti-browning agents. Australian growers and processors can now produce and market pre-peeled potatoes without sulphur dioxide for the domestic market. It is expected that overseas markets especially Asia would permit the marketing of potatoes prepared by the developed preservation system since most of the ingredients are currently classified as GRAS (Generally Regarded As Safe) substances.

TECHNICAL SUMMARY
(Confidential)

This project was conducted in order to develop and evaluate the effectiveness of an integrated processing, packaging, and controlled storage and handling as an alternative to freezing and/or the use of sulphur dioxide in extending the shelf-life of fresh peeled potato products.

The project has developed and tested a novel system for preserving the quality and extending the shelf-life of pre-peeled potatoes up to 2 to 4 weeks without the use of sulphur dioxide. The developed system integrates the following technologies: (i) encapsulation of the potato with an edible coating, (ii) incorporation of ascorbic and citric acid-based anti-browning agents in the coat, (iii) packaging in semi-permeable films, and (iv) low temperature storage. Shelf-life trials using commercially knife-peeled, steam-peeled, and abrasive-peeled potatoes showed inhibition of both enzymatic browning and microbial growth of up to 3 weeks at 4°C and up to 4 weeks at 1°C. Current shelf-life of peeled potatoes treated with sodium metabisulphite and vacuum packaged is about a week. Challenge experiments conducted by inoculating the potatoes with selected microorganisms have demonstrated the effectiveness of the developed system in guaranteeing the quality and safety of pre-peeled potatoes.

Enzymatic browning and microbial growth were found to be the main factors limiting shelf-life of pre-peeled potatoes. Sulphur treated and vacuum packaged potatoes were limited in shelf-life by anaerobic fermentation with associated production of off-odours and flavours. Potatoes processed and packaged using the developed preservation system were found to be limited in shelf-life by the growth of yeasts. Further extension in shelf-life can be achieved by the incorporation of approved level of organic preservatives in the coating.

Peeled potatoes packaged in semi-permeable films were found to be limited in shelf-life by enzymatic browning due to the presence of low levels of oxygen in the package headspace. Hue angle computed from Hunter's *L, a, b* values was found to be a practical objective measure of enzymatic browning and shelf-life in peeled potatoes.

The final processing, packaging and storage protocol has been verified to be applicable to potatoes peeled commercially by steam and abrasive systems. Steam peeled potatoes which have more severe tissue damage compared with mechanically peeled potatoes were preserved up to 15 days at 4°C by the developed preservation system. By comparison, untreated control samples exhibited a shelf-life of less than a day due to "after-cooking darkening". Addition of sodium acid pyrophosphate (SAPP) which is generally recommended for heat treated potatoes did not offer additional protection against "after cooking darkening".

The new preservation system in its present form was found to be ineffective in preserving lye-peeled potatoes. The presence of residual sodium hydroxide on the surface of the lye-peeled potatoes hindered the effectiveness of the developed preservation system.

Food Science Australia has successfully applied for the variation of Australia and New Zealand Food Authority (ANZFA) Food Standards Code to permit the use of edible coating and associated anti-browning agents. Australian growers and processors can now produce and market pre-peeled potatoes without sulphur dioxide for the domestic market. It is expected that overseas markets especially Asia would permit the marketing of potatoes prepared by the developed system since most of the ingredients are currently classified as GRAS (Generally Regarded As Safe) substances.

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1.0 INTRODUCTION

Consumers desire for convenience and freshness has created a market for new products such as pre-prepared (washed, peeled and/or sliced) potatoes for boiling. However, these fresh products currently rely heavily on the use of sulphur dioxide and its derivatives. Sliced potatoes for French fries are still relying on frozen storage and handling, a process which is well documented to cause undesirable textural changes.

Value-adding for Increased Consumption

A market research conducted in 1993 on behalf of the Australian Potato Industry Council and supported by the Horticultural Research and Development Corporation revealed that a significant proportion of the population were not satisfied with the quality of potatoes presented for sale. The study also showed that consumption of fresh potatoes was much lower by people up to the age of 40 than by people in the 50+ age category. Probably the marketing of fresh potatoes in pre-prepared formats (whole peeled, wedges, potato balls etc) could serve an impetus in increasing the consumption of potatoes.

Glycoalkoloids

Potatoes produce protective chemicals called glycoalkaloids to defend themselves from insects and fungi. Glycoalkaloids occur mainly in the leaves, stems and sprouts of the potato plant and are normally found at very low levels in potato tubers. However damaged potatoes or those with pronounced greening may contain high levels of glycoalkaloids which may cause food poisoning if consumed.

A case of food poisoning in NSW in 1994 which affected five people at a seafood restaurant has been attributed to the consumption of hot chips made from green and sprouting potatoes (Anonymous, 1996).

Glycoalkaloid levels are not affected by high cooking temperatures encountered in baking or frying processes and are only slightly reduced by freezing or dehydration.

Although adequate peeling of potatoes could reduce the consumption of glycoalkaloids from "green" potatoes, it is strongly recommended that processors source non-green tubers in producing pre-prepared potato products (Mondy and Gosselin, 1988).

Factors Limiting Shelf-Life of Peeled Potatoes

There are two (2) main factors limiting shelf-life in minimally or pre-prepared fresh potatoes: (i) physiological disorders, mainly enzymatic browning; and (ii) microbiological spoilage. Generally, shelf-life in peeled potatoes packaged under vacuum or low oxygen concentration would be limited by microbiological spoilage as indicated by the fermented off-odours. In comparison, peeled potatoes packaged in permeable packages which maintain at least 2% oxygen in the package headspace would be limited in shelf-life by enzymatic browning. In terms of product safety, the use of permeable packages is highly recommended to reduce the risk of developing conditions conducive for the growth of anaerobic pathogens (*e.g. Clostridium botulinum*).

The mechanism and various factors affecting the development of enzymatic browning are discussed in the following chapter. Various technologies for controlling enzymatic browning in fresh peeled potatoes are also presented.

The main objective of this project was to develop and evaluate the effectiveness of an integrated processing, packaging, and controlled storage and handling as an alternatives to freezing and/or the use of sulphur dioxide in extending the shelf-life of peeled fresh potato products.

2.0 Literature Review

Enzymatic browning is a major problem with pre-peeled potato products as it cause deleterious changes in the appearance and organoleptic properties of pre-peeled potatoes, resulting in shorter shelf life and a decrease in the market value. This problem would be more evident once sulfite is banned for this product as is expected in the medium term. Currently available alternatives to sulfites do not meet industry needs for product shelf life without the use of vacuum packaging.

2.1 Mechanism of Enzymatic Browning

The formation of pigments due to enzymatic browning is initiated by the enzyme polyphenol oxidase (PPO; monophenol, L-DOPA: oxygen oxidoreductase; EC 1.14.18.10), also known as tyrosinase, phenol oxidase, monophenol oxidase, or cresolase. Endogenous PPO is present in potatoes and other foods that are sensitive to oxidative browning including apples, mushrooms, fruit juices and wines.

Enzymatic browning is the result of the PPO-catalysed oxidation of mono- and diphenols to o-quinones (Figure 2.1). PPO is a mixed function oxidase that catalyses both the hydroxylation of monophenols to diphenols (cresolase activity) and the subsequent oxidation to o-quinones (catecholase activity). The o-quinones are highly reactive compounds and can polymerise spontaneously to form high-molecular-weight compounds or brown pigments (melanin), or react with amino acids and proteins that enhance the brown colour produced (Walker, 1977; Vamos-Vigyazo, 1981).

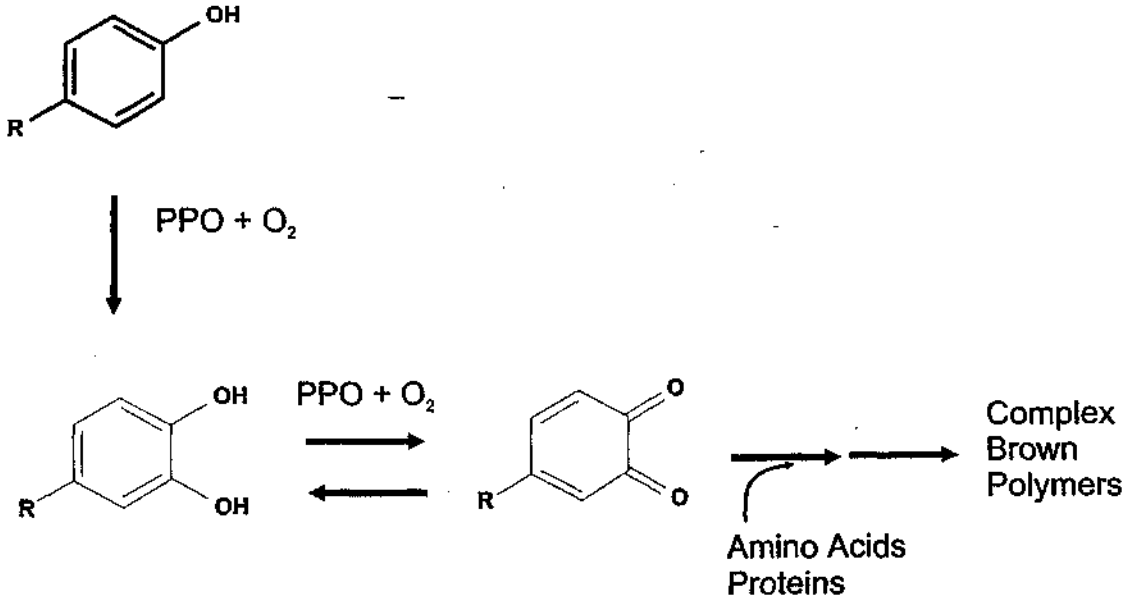

Fig. 2.1. Schematic of the initiation of browning by polyphenol oxidase (Walker, 1977)

In an uncut or undamaged vegetable, the natural phenolic substrates are separated from the PPO and browning does not occur. Once the vegetable tissue is cut or damaged and exposed to air, rapid browning occurs due to the enzymatic oxidation of phenols to orthoquinones.

Enzymatic browning occurs in the presence of four essential components: oxygen, enzyme, copper, and substrate. In order to have some control over enzymatic browning, one or more of the essential components must be eliminated or limited from the reaction.

2.2 PPO and its Substrates in Potatoes

2.2.1 Effects of cultural practices on PPO

During the growth period of potatoes, PPO activity was found to increase and phenolic content decrease in the first year of the two years investigated (Mondy et al. 1960). In general, later harvested potatoes showed stronger discolouration. Cultural practices also influence discolouration of raw potato flesh. A strong negative correlation between potassium content of the tubers sampled at harvest and enzymatic discolouration was reported by Baerug and Enge (1974). Fungicide pentachloro-nitrobenzene was reported to reduce browning in potatoes by lowering the level of tyrosine content. Maleic hydrazide, a sprouting inhibitor was found to increase the susceptibility of the tubers to bruising and discolouration, probably by modifying lipid composition (Mueller and Mondy, 1977).

2.2.2 Effects of sprout inhibitors

Gamma-irradiation used to prevent sprouting was reported to increase browning, while it decreased ascorbic acid content (Tatsumi et al. 1974; Ogawa and Uritani, 1970). The increase tendency to discolouration was interpreted as a result of cell damage, solubilisation of cell-bound enzyme, and easier access to its substrates, as well as lack of quinone reduction by ascorbic acid.

2.2.3 PPO during storage

PPO activity and polyphenol content (substrate) are not uniformly distributed in the potato tuber. PPO activity is generally higher in the peel and eyes, and phenolic compounds are present in high concentration in hilium, eyes, and peel (Amberger and Schaller, 1973). Chlorogenic acid could be detected only in the eyes and peel and in adjacent cortex. The distribution patterns were found to be cultivar dependent (Amberger and Schaller, 1973; Weaver et al. 1978). During storage, PPO activity and polyphenol content increased in the outer parts, chlorogenic acid content increased at low storage temperatures. Interestingly, PPO activity decreased in the inner parts of the tubers (Weaver et al. 1978). Since, both PPO activity and polyphenol content would be high in the outer parts of the tubers, it is generally expected that tubers stored for long periods at low temperatures would exhibit higher rates of browning when peeled or damaged compared to tubers stored for short duration.

2.2.4 Other factors affecting PPO and enzymatic browning

The rate of discolouration in potato tubers was reported to be dependent on both the cultivar and storage temperature (Heilinger et al. 1963). Some cultivars showed minimum discolouration on storage at 7°C, others at 4°C. Therefore, recommendations on storage temperature would be product specific.

Smith (1987) reported that storage temperature affects potato condition and composition. This view was supported by Sapers and Miller (1995) who observed that the tendency of pre-peeled potatoes to develop grey areas appeared to be greater when the raw material was refrigerated prior to treatment. In their direct comparison of products from potatoes stored up to 4 weeks at 4°C or 20°C, the incidence and severity of greying were less with those stored at higher temperatures. Mondy et al. (1966) also reported that Ontario and Pontiac potatoes stored at 10°C had significantly lower phenolic contents than did potatoes stored at 5°C. Katahdin potatoes, stored at 20°C, had a lower phenolic content than did potatoes stored at 5°C (Mondy et al. 1987). According to Smith (1987), storage of potatoes at higher temperatures would lower pH, due to formation and accumulation of organic acids, and would decrease or prevent discolouration. Transferring potatoes from 2°C to 20°C was reported to increase their citric acid content. Weaver et al. (1978) found that storing potatoes for 3 weeks at 20°C after 2 months at 7°C significantly lowered the PPO activity. These studies indicate that brief storage at 20°C prior to processing could reduce the tendency of the potatoes to undergo enzymatic browning or after-cooking darkening.

2.3 Fundamental Methods of Controlling Browning

For enzymatic browning to occur, four essential components must be present: oxygen, enzyme, copper, and substrate. In order to have some control over enzymatic browning, one or more of the essential components must be eliminated or limited from the reaction.

2.3.1 Elimination of oxygen

As browning is an oxidative reaction it can be retarded by the elimination of oxygen from the cut surface of the vegetables, however browning will occur rapidly when oxygen is re-introduced. Exclusion of oxygen is possible by vacuum packaging, modified atmosphere packaging, or by immersion in deoxygenated water, syrup, brine, or coating of the produce with surfactants (Obrero and Schnitzler, 1987). The use of low oxygen packaging can create conditions favourable for anaerobic fermentation and growth of anaerobic pathogens.

2.3.2 Chelation or elimination of copper

The phenolase enzymes contain copper as a prosthetic group which must be present for the browning reaction to occur. This copper prosthetic group is naturally present in vegetables and fruits. The use of chelating agents will slow the browning reaction, but will not completely eliminate its occurrence.

2.3.3 Heat inactivation of phenolase enzymes in vegetables

The most effective method for controlling enzymatic browning in canned or frozen vegetables is to inactivate the PPO by heat treatment. However, in fresh vegetables including pre-prepared potatoes, heat treatments can cause undesirable changes in texture such as softening.

PPO in vegetables and fruit tissues is generally inactivated by heat or by chemicals. Short exposure of PPO enzymes (i.e. in the tissues or in solution) to temperatures of 70 to 90 °C are generally sufficient for partial or total irreversible destruction of its catalytic function. Temperature tolerance of PPO depends to a variety of factors including pH and temperature, source of the enzyme, and degree of heat penetration.

Heat stability of PPO has been much less studied in relation to vegetables than in relation to fruits. The reported inactivation of PPO in green peas before freezing was achieved in 29 min at 80 °C, or 1 min at 95°C, while 2.5 min was required at 90°C (Krotov et al., 1971). PPO in green chillies was found to be remarkably heat resistant since the reported inactivation was only about 90% at 5 min at 90°C and 2 min at 100°C (Luhadiya and Kulkarni, 1978).

Heat treatment is the most commonly used method of inactivating most enzymes in vegetables intended for frozen storage. However, this method is not recommended for fresh pre-prepared vegetables including pre-peeled fresh potatoes intended for chilled or refrigerated storage.

2.3.4 Inactivation by low pH

Phenolase enzymes have an optimum pH in the range of 6.0 to 7.0. By lowering the pH of the media to below 3.0, enzyme activation is inhibited. However, maintenance of pH below 3.0 during storage of the product is very difficult to achieve in fresh vegetables without imparting an undesirable taste.

2.4 Application of antibrowning agents

A more common approach for the prevention of browning has been the use of antibrowning agents. Antibrowning agents are compounds that either act primarily on the enzyme or react with the substrates and/or products of enzymatic catalysis in a manner that inhibits pigment formation. The use of anti-browning agents in the food industry is constrained by considerations such as cost, effects on taste, flavour, colour, texture, and food regulatory issues.

2.4.1 Sulfiting agents

The most widespread method used for the control of browning in pre-peeled or cut potatoes is the addition of sulfiting agents. The major effect of sulfites on enzymatic browning is to reduce the *o*-quinones produced by PPO catalysis to the less reactive, colourless diphenols, thereby preventing the non-enzymatic condensations to precipitable pigments (Fig 2.2). Sulfiting agents also exhibit anti-microbial properties when used in sufficient concentration.

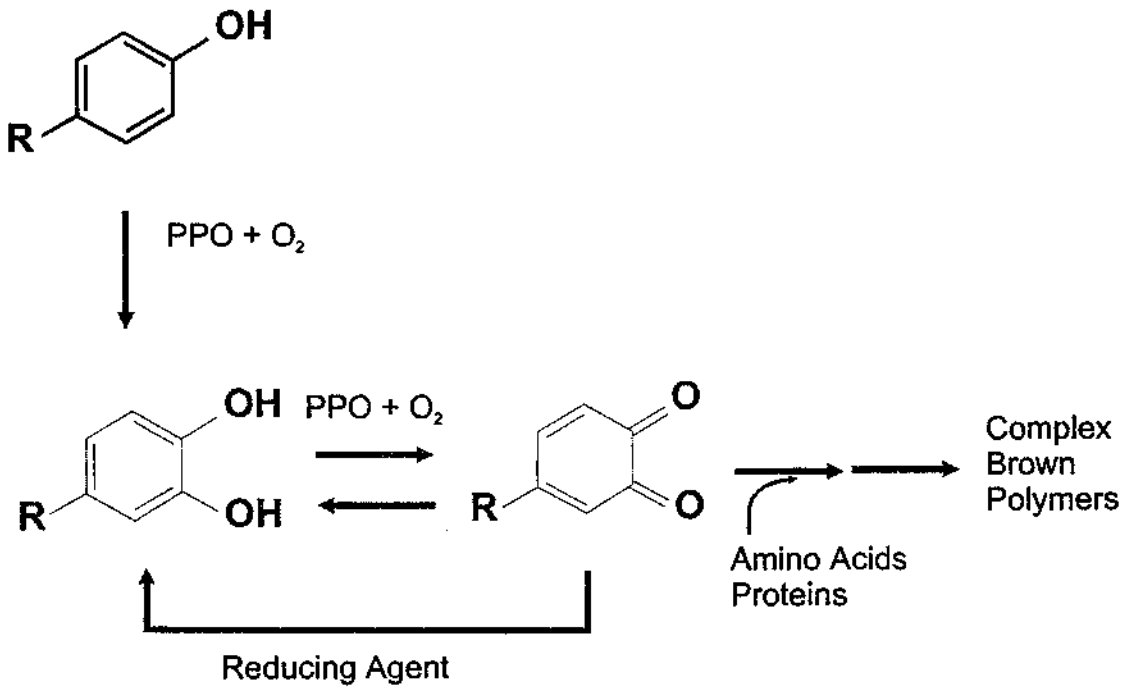

Fig. 2.2. The primary role of reducing agents such as sulfiting agents or ascorbyl compounds in the inhibition of enzymatic browning is to reduce the pigment precursors (quinones) to colourless, less reactive diphenols (Walker, 1977)

Although sulfites are very effective in the inhibition of enzymatic browning reactions, there are several disadvantages associated with their use in foods. Sulfites are known to cause adverse health effects, especially in certain sensitive individuals such as steroid-dependent asthmatics. Sulfites can also liberate sulfur dioxide gas and in enclosed areas, can be a major concern in terms of occupational and health issues during processing of the product. Sulfite residuals could also give negative effects on taste of the treated product (Taylor et al. 1986). The Food Standards Code permits the use of sulphur dioxide at a maximum level of 50 mg per kg of the product. However, the possible adverse health effects, increased regulatory scrutiny, and increase consumer awareness have created the need for practical and functional alternatives to sulfiting agents.

Table 2.1 gives a summary of antibrowning agents according to their classification as to their primary mode of action.

Table 2.1. Inhibitors of Enzymatic Browning

Classification	Examples
Reducing agents	Sulfiting agents Ascorbic acid and analogues Cysteine
Enzyme inhibitors	Substituted resorcinols Anions Peptides Aromatic carboxylic acids Aliphatic alcohols
Enzyme treatments	Oxygenases 0-Methyl transferases Proteases
Chelating agents	Phosphates EDTA
Acidulants	Citric acid Phosphoric acid
Complexing agents	Cyclodextrins

2.4.2 Reducing agents

The main role of reducing agents or antioxidants in the prevention of browning is their ability to chemically reduce the enzymatically formed or endogenous *o*-quinones to the colourless diphenols, or react irreversibly with the *o*-quinones to form stable colourless products analogous to the action of sulfites (Fig 2.2). The effect of reducing agents can be considered temporary because these compounds are oxidised irreversibly by reaction with pigment intermediates, endogenous enzymes, and metals such as copper. Thus, reducing agents are effective for the time period determined by their rate of consumption. The nonspecificity of reducing agents can also result in products with off-flavours and/or off-colours.

Ascorbic acid and erythorbic acid. Ascorbic acid and its isomer, erythorbic acid, have frequently been used inter-changeably as antioxidants in the food industry. The main role of ascorbic acid and erythorbic acid in the prevention of enzymatic browning is their ability to reduce o-quinones to diphenols (Fig. 2.2). The effects of ascorbic acid and erythorbic acid directly on the enzyme, PPO has been controversial and remains to be proven (Ponting, 1954; Muneta, 1981).

The mode of action of ascorbic acid and erythorbic acid is similar, however, ascorbic acid has been reported to be a more effective inhibitor of browning than erythorbic acid (Borentein, 1965; Bauerfeind and Pinkert, 1970). Nevertheless, recommended usage of the two reducing agents are the same (Borentein, 1965). The performance of erythorbic and ascorbic acid as inhibitors of enzymatic browning appears to be dependent on specific food system. In a comparison of erythorbic and ascorbic acid in apples, Sapers and Ziolkowski (1987) showed that both reducing agents were similar in effectiveness. A serious shortcoming of either ascorbic or erythorbic acid as antibrowning agent is that they are easily oxidised by endogenous enzymes, as well as decomposed by iron or copper-catalysed autoxidation to form dehydroascorbic acid. Ascorbic acid, when oxidised by these reactions or used at elevated levels, may exert prooxidant effects (Mahoney and Graf, 1979).

Ascorbyl phosphate esters. The rapid oxidation of ascorbic acid to dehydroascorbic acid has led to the development of ascorbic acid derivatives with increased stability. Ascorbic acid-2-phosphate and ascorbic acid-2-triphosphate have been investigated as stable substitute of ascorbic acid for the inhibition of browning at the cut surfaces of potatoes (Sapers and Douglas, 1987; Sapers et al. 1989; Sapers et al. 1989; Liao and Seib, 1990; Seib and Liao, 1987). Reports have indicated that phosphate esters were less effective than ascorbic acid in the prevention of browning of cut potatoes (Sapers et al. 1989).

Sulfhydryl compounds. Practical sulfhydryl-containing reducing agents may be limited to sulfur-containing amino acids such as *L*-cysteine, *L*-cystine, and *D,L*-methionine. *L*-Cysteine was reported to retard browning of pear juice concentrates when used at concentrations of 0.5 to 2*n*M (Montgomery, 1983). The primary mode of action of sulfhydrl compounds in the prevention of browning is explained in detail by Roberts (1959); Mason and Peterson, (1965); Pierpoint, (1966); Richard et al. (1991). The primary mechanism of action of sulfhyryl compounds in the prevention of browning is the reaction with the o-quinones formed by enzymatic catalysis to produce colourless and stable products. Unfortunately, the concentrations of cysteine necessary to achieve acceptable levels of browning inhibition have negative effects on the taste of the treated foods.

2.4.3 Chelating agents

The enzyme PPO contains copper in its active site. In the context of PPO-catalysed browning, chelating agents are believed to either bind to the active site coper of PPO or reduce the level of copper available for incorporation into the holoenzyme.

EDTA. Ethylenediaminetetraacetic acid (EDTA) or its sodium salt is widely used in the food industry as a metal chelating agent. As an antibrowning agent, EDTA is generally used in combination with other agents to eliminate browning (Table 2.1).

Phosphate-based compounds. Sodium acid pyrophosphate, polyphosphate, metaphosphate and "Sporix" (an acidic polyphosphate mixture with a 3 dimensional network structure) have been used as antibrowning agents of freshly peeled vegetables in a patent application (Gardner et al. 1991). Phosphate-based agents are typically used at levels of 0.5-2% (w/v) and in combination with other antibrowning agents (Table 2.1). These compounds are not in extensive use because they impart a bitter after-taste on the treated products.

2.4.4 Acidulants

The pH optimum of PPO activity varies with the source of the enzyme and the particular substrate but in most cases it has an optimum pH in the range of 6 to 7; the enzyme is inactive below pH 4.0 (Aylward and Haisman , 1969). The role of acidulants is to maintain the pH below that necessary for optimal catalytic activity.

Citric acid. The most widely used acid in the food industry for the prevention of browning is citric acid. Citric acid may have dual inhibitory effect on PPO by reducing the pH and by chelating the copper at the active site of the enzyme. Citric acid is often used in blended products in combination with other antibrowning agents (Table 2.1).

Other alternatives to citric acid are organic acids such as malic, tartaric acids, and inorganic acids such as phosphoric and hydrochloric acids.

2.4.5 PPO Inhibitors

The following are some literature reports on specific PPO inhibitors with specific practical relevance to food use.

Substituted resorcinols. 4-hexylresorcinol, a novel water-soluble, stable compound, non-toxic and non-carcinogenic is a potential inhibitor of PPO in potatoes and other vegetables that are prone to enzymatic browning. 4-hexylresorcinol is "generally recognised as safe" (GRAS) for use in the prevention of shrimp melanosis (McEvily et al., 1991; Iyangar and McEvily, 1992). Preliminary results of McEvily et al (1991) indicate that 4-hexylresorcinol also inhibits the browning of fresh and dried apple and potato slices. At the present, the use of 4-hexylresorcinol is permitted in shrimp, but is not allowed to be used on fresh peeled potatoes.

Aromatic carboxylic acids. Aromatic carboxylic acids are inhibitors of PPO due to their structural similarities to its phenolic substrates (Krueger, 1955). Cinnamatic acid and its analogues *p*-coumaric, ferulic and sinapic acids were reported to be potent inhibitors of apple PPO (Walker, 1975). Cinnamic acid (or its more soluble sodium salt) at levels of 0.01% or less was reported to be the most effective antibrowning agent for providing long term storage of fresh apple juice. The tendency of cinnamic acid and its sodium salt to induce browning is a major problem with the use of these compounds. The slow increase in the browning of the food suggests that the exogenous cinnamate is converted to a PPO substrate by cinnamate hydroxylases or other enzymes involved in the biosynthesis of polyphenols (Robinson, 1983).

Aliphatic alcohols. Inhibition of PPO by ethanol has been reported, but inhibition by other aliphatic alcohols was not studied extensively until more recently by Valero et al. (1990). The inhibition was reported to increase with the number of carbon atoms of the aliphatic alcohol (from one to five carbon atoms). The order of effectiveness for various alcohols appeared to be primary>secondary>tertiary alcohols.

Amino acids, peptides and proteins. Inhibition of browning in apple slices and model systems by honey was studied by Lee and Kime (1990). The results of Joslyn and Ponting (1987) suggest that honey contains inhibitors of PPO in addition to sugars. The compound responsible for the inhibition of PPO appeared to be a small peptide with approximate molecular weight of 600.

Proteins, peptides or amino acids can affect PPO-catalysed browning by direct inhibition of the enzyme or by reaction with the quinonoid products of PPO catalysis. A detailed study on the effects of protein (bovine serum albumin), protein hydrolysate (casein hydrolysate) and *L* amino acids on the activity of PPO from avocado, banana and mushroom was reported by Kahn (1985). Of all the amino acids reported, L-cysteine was reported to be the most effective with a reported 100% inhibition obtained with about 0.4 *m*M solution.

Anions. Inorganic halides have been reported to inhibit PPO, but other anions such as sulfate or nitrate have no effect (Lerner, 1952). The inhibition by halides is pH dependent and decreases as the pH is increased, with maximum inhibition in the pH range of 3.5 to 5.0 (Krueger, 1955). The order of decreasing inhibitory power of the halides has been reported to be F>Cl>Br>I.

Of the halide salts, sodium and calcium chloride at concentrations of 2 to 4% (w/v) are the compounds most commonly used in the food industry for the inhibition of browning (Steiner and Rieth, 1989). Use of calcium salts has the added advantage of maintaining the firmness of the pulp tissue by interacting with the pectin in the cell walls of the treated food. Calcium chloride is often used in blended products in combination with other antibrowning agents (Table 2.1).

2.4.6 Complexing Agents

Cyclodextrins. A patent has been awarded covering the use of cyclodextrins as inhibitors of enzymatic browning (Hicks et al. 1990). The cyclodextrins inhibit browning by the formation of inclusion complexes with or entrapment of PPO substrates or products. Cyclodextrins can also be used in combination with other known antibrowning agents. Potential drawbacks include the non-specificity of inclusion complex formation, resulting in the removal of flavour or colour compounds present in low concentrations. From a regulatory stand point, cyclodextrins are not permitted for use in foods at present.

Chitosan. Chitosan, a natural polymer of *N*-acetylglucosamine, inhibits the enzymatic browning of apple juices (Sapers, 1991). The mechanism of action is unclear, but may involve adsorption of PPO, its substrates or products, or a combination of such processes. McEvily and Iyangar (1992) suggested that the use of chitosan would be limited to liquid systems.

2.5 Combination of Antibrowning Agents

Since the mechanism of inhibition of various antibrowning agents are different, combination of various types of antibrowning agents may result in additive or synergistic effects that could enhance the inhibition of browning in various foods including pre-peeled potatoes. In many cases, the enhanced activity of the combined ingredients is additive, although synergism has been claimed for several blends of antibrowning agents. A typical combination could include a reducing agent (e.g. ascorbic acid), an acidulant (e.g. citric acid), and a chelating agent (e.g. EDTA). Table 2.2 is a list of representative commercial blends of antibrowning ingredients.

Table 2.2 List of commercial antibrowning ingredients

Commercial Blend	Ascorbic acid	Citric acid	Calcium Chloride	Sodium Chloride	Phosphate	Dextrose
Flavor Brite	YES	YES	YES	YES	YES	YES
Freshway	YES	YES	YES		YES	
Potato Fresh[a]	YES	YES			YES	
Sexton Antioxidant	YES	YES	YES			
Pfizer CE-101P	YES[b]	YES				
Color Fresh	YES	YES				YES
Snow Fresh	YES	YES	YES		YES	
Salad Fresh[c]	YES[d]	YES			YES	YES
Crisp & Fresh		YES[e]		YES		

Reference: Kim and Taubb (1988)

[a]*Contains cysteine hydrochloride.*
[b]*Added as iso-ascorbic (erythorbic) acid.*
[c]*Contains aluminium sulfate*
[d]*Added as sodium ascorbate*
[e]*Added as sodium citrate.*

Several sulfite substitutes, mostly formulations of ascorbic acid (AA) or erythorbic acid (EA) in combination with citric acid, phosphates, preservatives, and other adjuncts, have been tested, but these were found to be less effective as sulfites (Duxbury, 1987; Langdon, 1987; Santerre et al., 1991).

Most combinations of antibrowning agents that are commercially available or cited in the literature are ascorbic acid-based compositions.

A combination of ascorbic acid, citric acid, and potassium sorbate in conjunction with vacuum packaging was reported by Langdon (1987) to slow browning of potato slices. However, the onset of browning was reported to be very fast once the package is opened. Packaged potatoes were also reported to developed a large number of microbial populations after few days at 4°C.

Warren (1991) have claimed in a patent application that solutions containing ascorbic acid (0.25 to 1%), calcium chloride (0.5 to 1%), citric acid (0.25 to 1%), and sodium acid pyrophosphate (0.5 to 2%) could inhibit browning of potatoes, apples, and lettuce.

Dipping of whole pre-peeled potatoes in a solution containing erythorbic acid, sodium chloride, and sodium pyrophosphate, followed by packing in ascorbic acid, sorbic acid, and calcium

chloride, resulted in potatoes that were less brown and had lower microbial counts than potatoes treated by the customary bisulphite dip procedure (Cash et al., 1991).

Other blends that have been reported to be antibrowning agents but do not contain ascorbic or erythorbic acid include solutions of cysteine and citric acid, and citric acid, sodium chloride, and calcium chloride (Steiner and Rieth, 1989; Cherry and Singh, 1990)).

A more comprehensive listing of commercially available antibrowning blends and their constituent ingredients can be found in a compilation of Kim and Taub (1988).

2.6 Technologies for Controlling Browning and Shelf-life Extension

2.6.1 Conventional Dipping and Vacuum Packaging

There are several conventional treatments still being used commercially to prevent enzymatic browning of pre-peeled potatoes. These treatments include vacuum packaging, packing and shipping peeled tubers in pails under a cover solution containing citric acid and sorbic acid. Preservation systems based on the above-mentioned approach could be costly, inconvenient, and may induce health risks because of the development of anaerobic conditions conducive to the growth of pathogenic organisms.

2.6.2 Pressure and Vacuum Infiltration

Others have tried to increase the effectiveness of ascorbic acid-based solution by increasing the penetration of the solution into the cellular matrix of the potato pieces. The shelf-life of Brown Russet potato plugs was extended by 2 to 4 days when treated by pressure infiltration at 103 kPa with solutions containing 4% ascorbic acid, 1% citric acid, and 0.2% calcium chloride, when compared with dipping at atmospheric pressure for 5 min. However, the same pressure infiltration procedure has no effect on potato dice according to Sapers et al. (1990). This ineffectiveness could be due to the inability of the antibrowning solution to penetrate and stay on the damaged sections of the potatoes.

2.6.3 Heated Application of Antibrowning Agents

In another attempt by Sapers and Miller (1995) to increase the effectiveness of ascorbic/citric acid solution as browning inhibitor for pre-peeled potatoes, they heated their solution to 45-55°C during the dipping process. Their combined treatment of dipping abrasively-peeled potatoes in 45-55°C solution based on ascorbic/citric acid for 5-20 min, followed by a 5 min dip in another solution containing 4% ascorbic acid, 1% citric acid, 1% sodium acid pyrophosphate (20°C ambient) inhibited potato discolouration for 14 days at 4°C. The major disadvantage with their proposed 2-dip method was the reported formation of a layer (several mm thick) which was more tender than the underlying tissue. In some cases, a shell-like layer of toughened tissue separated from the underlying tissue which during handling and cutting created an unsightly product and interfered with mashing. The proposed treatment is also ineffective for lye-peeled potatoes. Overall, this technique is expected to find little acceptance in the vegetable industry.

2.6.4 Use of Vegetable Gums

In a patent application by Wyss et. al. (1990), a combination of thixotropic gum (*i.e.* xantham, guar, tragacanth, etc.) was cited to be effective in reducing deterioration and browning of vegetables used in salad bars and prepared salads sold in fast food restaurants.

2.6.5 Inactivation by Low pH

Based on the activity of enzymes prepared from various genera and cultivars of various fruit and vegetables, the majority of the enzyme preparations exhibited a single pH optimum of activity. In potatoes, optimum pH was reported to be about 5.8 (Schaller, 1972; Mihalyi et al. 1976). By lowering the pH of the media to below 3.0, enzyme activity is inhibited. However, maintenance of pH below 3.0 during storage of the product is very difficult to achieve in fresh vegetables including pre-peeled potatoes.

Packing in citric acid solution after application of browning inhibitors was suggested by Santerre et al.(1991). However, this procedure could produce anaerobic conditions detrimental to the natural respiration of the product.

2.7 Modified Atmosphere and Vacuum Packaging

2.7.1 Vacuum packaging

Vacuum packaging removes almost all atmospheric gases from within the package. Vacuum packaging alone (Kiejbets, 1981), or combined with dipping in ascorbic acid-based solutions (Langdon, 1987), has been used to extend the life of peeled-whole and chipped potatoes. Vacuum packaging is not a very attractive option because anaerobic conditions may result in off-flavour development in pre-peeled potatoes (McLachlan and Stark, 1985), and could facilitate growth and toxin production by *Clostridium botulinum* at storage temperatures >5°C (Tamminga et al., 1978).

Although sulfite treatment is very effective in inhibiting browning of pre-peeled potatoes, vacuum packaging using high barrier film is required to achieve a shelf life of about 9 days at 4°C (Giannuzzi et al. 1988). Aside from health and regulatory issues, the use of sulfite and vacuum packaging are usually associated with softening of potatoes especially at higher SO_2 residues, and fermentation as indicated by development of appreciable alcohol levels (Francis and Amla, 1961).

2.7.2 Modified atmosphere packaging

Enzyme action can be inhibited to varying degrees by altering the levels of CO_2, O_2, and CO in the package atmosphere. For example, exposure of crude extracts and purified preparations of PPO from Red Delicious apples to about to 30% CO_2 were reported to result in about 80% inhibition.

In shredded lettuce, broccoli and cauliflower florets, Reyes and Gould (1993) reported that CO_2 levels of about 18% in the presence of about 3% O_2 during controlled atmosphere (CA) storage can inhibit enzymatic browning reactions for at least 15 days at 4°C. No physiological disorder was detected during the duration of the test which was 15 days. Kader et al. (1973) cited the effectiveness of an atmosphere containing 1% CO, 1% CO_2, and 5-10% O_2 in preserving the

colour of lettuce. By contrast with the reported benefits of CA storage and MAP, little or no advantage was reported on the prevention of enzymatic browning in potato strips (McLachlan and Stark, 1985).

The work of O'Beirne et al. (1987) have indicated that modified atmosphere packaging (3-4% CO_2; <3% O2) combined with antioxidants 9-10% ascorbic acid) is not particularly useful for short-term storage of fresh potato chips at 5°C. Even at low oxygen concentration (≤3%), dipping in relatively high concentration of ascorbic acid (10%) was still required to control discolouration for 7 days at 5°C. At this concentration ascorbic acid, fried potato strips produced dark colour which is a disadvantage since lightness of colour is an important index of fried chips quality. There is a concern that low levels of oxygen (0-<2%) might result in off-flavours development due to anaerobic respiration.

2.8 Surface Digestion

Since the severity of browning in pre-peeled potatoes appears to be related to the extensive surface damage caused by peeling with lye, steam, or abrasion, Sapers and Miller (1992) suggested the removal of the damaged tissue by some digestion procedure prior to the application of conventional browning inhibitors. This concept is not new. As early as 1957, a patent was issued to the USDA Western Regional Centre for a low temperature lye digestion process to remove the undesirable cooked surface layer from lye-peeled potatoes (Harrington, 1957). Digestion treatment was reported to be applicable to both abrasion- and steam-peeled potatoes.

Sapers and Miller (1992) reported that lye digestion of the peeled tubers in combination with an immersion treatment based on ascorbic acid can extend the shelf-life of pre-peeled potatoes to at least 10-13 days at 4 °C compared to only 3 days shelf-life of control samples treated with ascorbic acid. The lye digestion solution was reported to be 14-20% NaOH at 20-55°C for 1-13 minutes. The recommended antibrowning solution was 4% ascorbic acid, 1% citric acid, 1% sodium acid pyrophosphate (SAPP) and 0.2% $CaCl_2$ for 5 minutes. The major drawback using this lye surface digestion procedure was the reported weight loss of at least 13% depending on the digestion time and temperature.

Digestion of pre-peeled potatoes with strong mineral acids were also reported by Schwank (1992) and Sperber (1992).

2.9 Genetic Engineering

A more long-term approach to preventing browning of vegetables and fruits is to develop anti-PPO gene (O'Neill, 1995). CSIRO's Division of Horticulture have suggested that that an anti-sense PPO gene, a gene whose DNA code countermands the PPO gene's instruction to make the enzyme could be the solution in reducing enzymatic browning in vegetables.

2.10 Peeling Procedure

Processors of potatoes usually peel with lye, steam or abrasive systems. Abrasion peeling results in higher losses and generally suitable for low capacity operations. Lye peeling may be done by immersing the potatoes from 2- 6 minutes in a lye solution of 15-25% at 87 - 93°C. The time of immersion, concentration and temperature of solution would depend on the age of the tuber and the variety. At present, there is a trend against the use of lye peeling because of environmental issues. Continuous or batch steam peeling equipment may be used.

In steam peeling, potatoes are briefly exposed to high temperature steam followed by a sudden drop in pressure. When that occurs, the moisture beneath the skin of a product flashes into the steam, expands and loosens or bursts the skin. Typical exposure of root type vegetables is 15 to 30 seconds at 220 psi (1517 kPa) steam pressure. Exposure to steam is generally followed by cooling and peel removal in a high pressure water spray. An example is the SES Steam Peeler Series from FMC. In most cases, potatoes are discharged from the peeler into a washer to complete removal of the peel by water sprays.

2.11 Shelf-Life

The shelf-life of pre-prepared potatoes based on microbial count was defined in this study as the time of refrigerated storage at which the product reaches total aerobic counts of 10^6 cfu/cm^2. At these levels of contamination, potatoes become soft and slimy, and therefore unacceptable to consumers (Garrick, 1969).

The shelf-life of pre-peeled potatoes can also be limited by the presence of dark surface discolouration due to enzymatic browning. The objective and subjective limits of surface discolouration are discussed in detail in section 3 of this report.

3.0 METHODOLOGY

3.1 Preliminary Studies on Whole Peeled Potato

3.1.1 Preliminary vacuum packaging trial

The objective of this preliminary trial was to assess the potential of 2 commercially available sulphite-free antibrowning mixtures reported in the literature. *Sebago* tubers about 120g each were manually-peeled by knife, rinsed in water (15°C), and equally divided into 3 lots for various treatments. Peeled tubers were immersed for about 2 minutes in one of the treatments listed in Table 3.1. After drainage of excess solution, peeled tubers were placed in standard Cryovac bags (50 *u*m polyolefin multilayer Cryovac B-900) and sealed under vacuum (-1 bar) using a Webomatic vacuum packaging machine (Model E500, Germany). All samples were stored at 1.5°C for the duration of the storage test.

Table 3.1 Treatments baths for peeled potatoes

Treatment Code	Ascorbic acid (% w/v)	Citric Acid (% w/v/)	SAPP (% w/v)	Calcium chloride (% w/v)	Potassium sorbate (% w/v)
A*	4.0	1.0	1.0	0.2	-
B@	0.5	0.5	-	-	0.2
Control+	-	-	-	-	-

A* - formulation of Sapers and Miller (1992)
B@ - formulation of Langdon (1987)
Control+ - Water-dipped

Treatment B contained 0.2% (w/v) potassium sorbate to control yeasts and mould growth. In making the treatment B, potassium sorbate was added first and when it was totally dissolved, the citric acid and the ascorbic acid were added simultaneously.

3.1.2 Preliminary modified atmosphere packaging trial

The objective of this preliminary study was to assess the potential of modified atmosphere packaging (MAP) in preserving the quality of fresh peeled potatoes stored at 4 °C.

Manually peeled *Desiree* tubers were divided into three (3) lots and treated in various ways as described in Table 3.2. Treatments GA and GW were prepared by placing 4 peeled tubers in a permeable polyethylene bags (50*u*m LDPE, low density polyethylene) followed by partial vacuum and gas-flushing with pre-determined levels of CO_2 and N_2. A gas flushing machine (FreshPac AVS400) with a "snorkel" port for vacuum and gas-flushing was used in this study. The size of the pouch used in this study was about 210mm x 245mm.

Table 3.2 Preliminary MAP treatments

Treatment	Antibrowning Solution (%w/v)	Packaging
GA	4%AA, 1%CA, 1%SAPP, 0.5%$CaCl_2$	40%CO_2/3%O_2
GW	Water	40%CO_2/3%O_2
Control	Water	Air

3.2 Comparison of vacuum and gas packaging

This study was conducted to evaluate the effects of selected combinations of anti-browning agents, blanching, vacuum and gas packaging on the microbiological quality, colour changes (*i.e.* brown discolouration), and other factors affecting the acceptability of peeled whole potatoes.

Table 3.3 Summary of combination treatments used for whole peeled potatoes

Treatment	Dipping solution	Blanching	Packaging
Control	Water	None	Sealed in air
VA	Water	None	Vacuum
VS	Antibrowning agents	None	Vacuum
BA	Water	70°C/10 min	Vacuum
BS	Antibrowning agents	70°C/10 min	Vacuum
MA	Water	None	40%CO_2/3%O_2
MS	Antibrowning agents	None	40%CO_2/3%O_2

Vacuum Treatments. Combination treatments based on vacuum packaging included the following:

(i) Vacuum packaging only - VA
(ii) Antibrowning solution + vacuum packaging - VS
(iii) Vacuum packaging + blanching - BA
(iv) Antibrowning solution + vacuum packaging + blanching - BS

Treatment VA (vacuum packaging only) refers to the dipping of peeled tubers in water for about 2 minutes, removing excess water by draining in a colander for 2 minutes and vacuum packaging. A Webomatic Vacuum Packaging machine set at -1 bar was used to vacuum packaged peeled tubers in a standard Cryovac barrier bag.

In treatment VS, tubers were dipped in the antibrowning solution (4% ascorbic acid, 1% citric acid, 1% sodium acid pyrophosphate, 0.5% calcium chloride) for about 2 minutes before vacuum packaging.

Tubers corresponding to treatment BA were prepared in a similar manner as treatment VA. After vacuum packaging, packaged samples were blanched in a water bath set at 70°C for 10 minutes. This approach is similar to "*sous vide*" cooking commonly used in pre-prepared meals in France. *Sous vide* means cooking under vacuum. Heat treatment of already packaged product eliminates the problem of product contamination during the blanching and handling process. Heat treatment can be a practical solution in preventing enzymatic browning by inactivating PPO enzyme in the potato tuber. A "boilable" cast polypropylene film (PP, 50 *u*m) supplied by W.R. Grace Australia was used in this study.

Samples corresponding to treatment BS (antibrowning solution + vacuum + blanching) were dipped initially for 2 minutes in anti-browning solution before being packaged and blanched as described in treatment BA.

Gas Packaging Treatments. Two treatments based on gas packaging were included in this preliminary trial. Treatment MA were prepared by dipping peeled potatoes for 2 minutes in water before gas packaging. In treatment MS, peeled potatoes were dipped for 2 minutes in antibrowing solution prior to gas packaging. Gas packaged samples were prepared by evacuating the packages by vacuum and flushing each bags with a selected mixture of nitrogen and carbon dioxide to give a gas composition of about 40% carbon dioxide, 3% oxygen and 57% nitrogen. The packages were made from 50*u*m polyethylene blend which has a reported oxygen transmission rate (OTR) of about 5,000 cc/m^2-day at 21°C (70%RH), and 2,500 cc/m^2-day at 2-4°C (90% RH). This type of film was selected to produce an equilibrium oxygen level of about 2-3%. The principle behind the use of high CO_2 was to produce a temporary inhibition of browning while maintaining an aerobic environment (2-3% oxygen). The inhibition may be temporary because carbon dioxide could permeate out of the package at a faster rate compared to the rate that oxygen from the air could enter into the package. The rate of carbon dioxide permeability compared to that of oxygen generally ranges from 3-5 times.

All samples during the test were stored at 4°C for a period of 3 weeks or shorter depending on their acceptability. Each treatments consisted of 4 replicate bags which contained 4 manually peeled *Sebago* tubers.

3.3 Effects of the coating and levels of antibrowning agents on peeled potatoes

The objective of this experiment was to determine the range of concentrations of selected anti-browning agents and the effectiveness of alginate based gel coating in inhibiting enzymatic browning in peeled whole potatoes.

Sound and firm *Sebago* potatoes about 130g (*Solanum tuberosum*) were hand-peeled, and then temporarily stored under water for 10-30 minutes. The coating and anti-browning agents were applied in two stages: (1) A general solution I, was an alginate solution (Appendix D); (2) Solutions II were combinations of various anti-browning agents and calcium chloride (2% w/v). Table 3.4 shows the various concentration of anti-browning agents in Solution II - 7 solutions (T_1 to T_7) excluding water dipping for control samples (T_8). All solutions were prepared at room temperature and stored at 4±0.5°C overnight. Each peeled potato tuber receiving the coating was immersed into Solution I for about 1-5 minutes, and allowed to drip, followed by immersion into Solution II which resulted in a clear homogenous coat/film over the entire surface of the potatoes. After draining in a colander, 4 peeled tubers (520g) were placed in a semi-permeable plastic bag (175 x 190 mm). Preliminary work suggested that this packaging film would could produce a useful aerobic equilibrium-modified atmospheres of about 1-10% O_2. All plastic packages were heat sealed using a manual sealer (Venus Model VH400). An additional treatment (T_8), to act as the control was prepared by dipping the peeled potatoes in water. There were 3 replicates per treatments. Treated samples and controls were stored at 4±0.5°C for as long as 22 days.

Table 3.4 Various treatments for whole peeled potatoes

Treatment	AA* (%w/v)	CA* (%w/v)	SAPP* (%w/v)
T_1	4	1	1
T_2	4	1	-
T_3	2	0.5	0.5
T_4	2	0.5	-
T_5	1	0.25	0.25
T_6	1	0.25	0.25
T_7	"Coating only"	N/A	N/A
T_8	"Water-dipped"	N/A	N/A

*Note: AA - Ascorbic acid; CA - Citric Acid; SAPP - Sodium acid pyrophosphate; T_1 to T_7 also contained 2% calcium chloride as a gelling agent.

Assessment for Visual Appearance:

Objective assessment. Treatment effectiveness was evaluated by measuring colour changes at the peeled surface of treated samples and controls during storage. To measure colour objectively, the CIELAB's "*L*" (light-dark), "*a*" (red-green) and "*b*" (yellow-blue) for a selected surface were measured using a Minolta Chroma meter, Model CR300 with a 8mm specimen port. For each treatment, a total of 18 measurements were taken (6 measurements per bag of sample). To evaluate the change in colour, hue angle was also calculated from the tristimulus data. Hue angle values of 0°, 90°, 180°, and 270° indicate red, yellow, green, and blue, respectively. Hue angle values close to 90° indicate browning.

Visual observation. A subjective visual evaluation was also conducted to assess the change in colour during storage. A scoring system described in Table 3.5 was used to subjectively assess the visual acceptability of fresh peeled potatoes. A colour score of "5" and below was considered unacceptable.

Table 3.5 Visual scoring system for fresh peeled potatoes

Score	Description
10	Extremely desirable, no defects
9	Very desirable, no browning, very slight drip
8	Desirable, no browning, slight drip
7	Slightly desirable, slight browning <50% of tubers, browned area <5mm diameter
6	Marginally acceptable, slight browning <50% of tubers, browned area >5mm diameter
5	Undesirable, moderate browning >50% of tubers, browned area >5mm diameter
4	Very undesirable, extreme browning and other defects

Package Headspace Analysis

Oxygen and carbon dioxide levels in the packages were measured by injecting 20 ml of gas sample drawn from the package into a "MAPtest 4000" gas analyser (HiTech Instruments, U.K.). The gas analyser uses a zirconia oxygen sensor and an infra-red carbon dioxide sensor. The accuracy of measurements was about ±1% of the reading.

Objective Texture Measurement

Compression tests (Lloyd, Model 1000R, U.K, 100 N load cell, crosshead speed 20mm/min, 8mm diameter flat plunger) were performed on a flat surface of 8 randomly selected potatoes (coat removed). The maximum load encountered during a 3 mm penetration on the surface was taken as a measure of firmness or softness of the potatoes.

3.4 Shelf-life of Coated Samples Under Various Packaging and Storage Conditions

The main objective of this study was to determine the shelf-life of coated potatoes packaged in either air or gas flushed prior to sealing. The effects of low temperature storage (*i.e.* 1 and 4°C) on product quality were also evaluated. A summary of treatments used in this section is given in Table 3.6.

Table 3.6 Packaging and storage combinations used for pre-peeled potatoes

Treatment	Packaging	Storage Temperature	Anti-Browning Agent
1C	Air	1°C	None
1A	Air	1°C	Yes
1G	Gas	1°C	Yes
4C	Air	4°C	None
4A	Air	4°C	Yes
4G	Gas	4°C	Yes

Approximately 150g of *Sebago* potato tubers were hand-peeled and prepared as described in section 3.3. The coating and anti-browning agents were applied in two stages: (1) Solution I was an alginate solution; Solution II consisted of ascorbic acid based antioxidants (Appendix D). All solutions were prepared at room temperature and stored at 4±0.5°C overnight. Each peeled potato tuber receiving the coating was immersed into Solution I for about 1-5 minutes, and allowed to drip, followed by immersion into Solution II which resulted in a clear homogenous coat over the entire surface of the potatoes. After draining in a colander, 6 peeled tubers were placed in a semi-permeable plastic bag (200 x 240 mm). Packages representing treatments 1A and 4A were manually heat sealed to simulate passive generation of MA by the natural respiration of the produce. Gas packaged samples (treatments 4G and 1G) were prepared by subjecting each package to partial vacuum and gas flushing using a Freshpac Model AVS gas packaging equipment (Freshpac Machinery, NSW). An initial concentration of 30% CO_2 and 5% O_2 was attained in these gas-flushed samples. Additional treatments (4C and 1C) acting as the control samples were prepared by

dipping the peeled potatoes in water followed by manual heat sealing using the same semi-permeable packaging material. Treated samples and controls were stored at either 4±0.5°C or 1±0.5°C for as long as 4 weeks.

Oxygen and carbon dioxide levels in the packages were measured by injecting 20 ml of gas sample drawn from the package into a "MAPtest 4000" gas analyser (HiTech Instruments, U.K.). The gas analyser uses a zirconia oxygen sensor and an infra-red carbon dioxide sensor. The accuracy of measurements is about ±1% of the reading.

Compression tests (Lloyd, Model 1000R, U.K, 100 N load cell, crosshead speed 20mm/min, 8mm diameter flat plunger) were performed on a flat surface of 8 randomly selected potatoes (coat removed). The maximum load encountered during a 3 mm penetration on the surface was taken as a measure of firmness or softness of the potatoes.

3.5 Comparison of the Coating System and Sulphur Dioxide Treatment

The objective of this study was to compare the novel process of combining coating and anti-browning agents with the traditional use of sodium metabisulphite solution in preserving the fresh appearance of peeled potatoes.

Coliban potatoes about 150g were hand-peeled with a sharp knife and then, temporarily stored in water for about 10-30 minutes. Peeled potatoes were divided into 3 lots for the following treatments: (1) "Coated" - samples coated with combinations of alginate and anti-browning agents, (2) "Sulfited" - samples dipped in sodium metabisulphite, and (3) Control - samples dipped in water.

Coated samples were prepared and packaged as described in section 3.3. Each peeled potato was immersed into Solution I (Appendix D) for about 1-5 minutes, allowed to drip, followed by immersion into Solution II which resulted in a clear homogenous coat over the surface of the potatoes. After draining excess solution, 6 coated tubers were placed in a semi-permeable plastic bag (200 x 240mm). All plastic bag were heat sealed prior to storage at 8±0.5°C.

Sulfited samples were prepared by immersing peeled potatoes in 1% solution of sodium metabisulphite (pH 4.6) for 2 minutes. Tubers were drained for 2-5 minutes, and 6 tubers were vacuum sealed using a Webomatic vacuum packaging machine (Model E50G) set at -1.0 bar. The plastic bags used for vacuum packaging were standard Cryovac barrier bags.

Control samples were dipped in water for about 2 minutes. After draining excess water, 6 tubers were placed in plastic bags and heat sealed. Samples were placed at 8±0.5°.

Quality changes were monitored regularly as described in section 3.3.

3.6 Synergistic and Additive Effects of Various Coating Components

The object of this experiment was to determine the individual and possible synergistic effects of a selected mixture of anti-browning agents and sodium alginate gel coating in inhibiting enzymatic browning in abrasively-peeled raw potatoes.

Approximately 8 kg of *Sebago* potatoes each weighing about 150g were peeled using an abrasive peeler (P102 Peeler by Pelatori Polivalenti of Italy). Peeled potatoes were washed using tap water and divided into 4 lots corresponding to the treatments shown in Table 3.7. The vegetable gum (coating) and anti-browning agents were applied in two stages as described in section 3.3. After draining in a colander, 4 peeled potatoes were placed in semi-permeable polyethylene blend plastic bag (175 x 190 mm). Preliminary work suggested that this packaging film would produce a useful aerobic equilibrium-modified atmosphere of about 2-10% oxygen. All plastic packages were heat sealed using a manual sealer (Venus Model VH400). An additional treatment (T1) which acted as a control was prepared by dipping the peeled potatoes in water. There were 4 replications per treatment. All samples were stored at 4±0.5°C for 21 days.

Table 3.7 - Treatments to assess effects of coating, anti-browning mixture and their combinations on abrasively-peeled potatoes

Treatment	Ascorbic Acid (%)	Citric Acid (%)	Sodium Alginate* (%)
T_1: Control	-	-	-
T_2: Anti-browning solution	2	0.5	-
T_3: Coat only	-	-	2.8
T_4: T_2 & T_3	2	0.5	2.8

Appendix D

3.7 Effects of the Levels of Anti-browning Agents in the Coating

The object of this experiment was to evaluate the effects of various amount of coating in combination with different mixtures of anti-browning agents.

Sebago potatoes each weighing about 150g were peeled using an abrasive peeler (P102 Peeler by Pelatori Polivalenti of Italy) in batches of 8kg. Peeled potatoes were washed using tap water and divided into 10 lots corresponding to the treatments shown in Table 3.8. The vegetable gum coating and anti-browning agents were applied in two stages: (1) Solution I contained various vegetable gum solutions (Table 3.8); and (2) Solution II was a combination of anti-browning agents based on ascorbic acid. All solutions were prepared at room temperature and stored at 4°C overnight. Each peeled potato receiving the coating was immersed into Solution I for about 5 minutes, and allowed to drip for about 20 seconds, followed by immersion into Solution II which resulted in a clear homogenous coat/film over the entire surface of the potatoes. It took about 10-20 minutes to complete the second immersion. After draining in a colander, 4 peeled potatoes were placed in semi-permeable polyethylene blend plastic bag (175 x 190 mm). All plastic packages were heat sealed using a manual sealer (Venus Model VH400). An additional treatment (T1) which acted as a control was prepared by dipping the peeled potatoes in water. There were 4 replications per treatment. All samples were stored at 4±0.5°C.

Treatment effectiveness was evaluated by measuring colour changes at the peeled surface of treated samples and control during storage. To measure colour objectively, the CIELAB's "*L*" (light-dark), "*a*" (red-green) and "*b*" (yellow-blue) for randomly selected surface areas were measured using a Minolta Chroma meter, Model CR300 with a 8 mm specimen port. To evaluate the change in colour, hue angle was also calculated from the tristimulus data ("a" and "b"). Hue angle values of 0°, 90°, 180° and 270 indicate red, yellow, green, and blue, respectively. Hue angle values close to 90° indicate more browning.

A subjective visual evaluation was also conducted to assess the change in colour during storage. A scoring system described in Table 3.5 of section 3.3 was also used to subjectively assess the visual acceptability of fresh peeled potatoes. A colour score of "5" was considered the end of shelf-life.

Table 3.8 - Treatments for whole peeled potatoes prepared using various coatings and anti-browning agents

Treatment	Solution I (coating)		Solution II*	
	Sodium Alginate	Viscosity	Ascorbic Acid (%w/v)	Citric Acid (%w/v)
T1 (Control)	-	-	-	-
T2	3% Type A	Low	1	0.25
T3	3% Type A	Low	2	0.50
T4	3% Type A	Low	4	1.00
T5	2% Type A & 1% Type B	Medium	1	0.25
T6	2% Type A & 1% Type B	Medium	2	0.50
T7	2% Type A & 1 % Type B	Medium	4	1.00
T8	3% Type B	High	1	0.25
T9	3% Type B	High	2	0.50
T10	3% Type B	High	4	1.00

Appendix D

3.8 Performance of Heat Soluble Coating

The object of this experiment was to evaluate the effectiveness of vegetable gum coatings based on agar or "agar-agar" solely or in combination with sodium alginate. The use of agar-agar solely or in combination with other coating components could produce a thermo-reversible coating for pre-peeled potatoes.

Previous sections have shown the effectiveness of combining sodium alginate coating with selected mixtures of anti-browning agents. In some situations, a coating that dissolves in hot water (*i.e.* thermo-reversible) could be an advantage. While coatings based on sodium alginate are mostly thermo-stable, coatings based on agar would be mainly thermo-reversible. Therefore, this study was conducted to investigate the levels of agar solely or in combination with sodium alginate that could preserve the colour and appearance of raw peeled potatoes.

Sebago potatoes each weighing about 150g were peeled using an abrasive peeler (P102 Peeler by Pelatori Polivalenti of Italy). Peeled potatoes were washed using tap water and divided into 8 lots

corresponding to the treatments shown in Table 3.9. The agar-based coating and anti-browning agents were applied in two stages: (1) Solution I was warm agar solution (60°C); and (2) Solution II was a combination of anti-browning agents based on ascorbic acid (Appendix D).

Each peeled potato receiving the agar-based coating was immersed into warm Solution I (about 60°C) for about 30 seconds, followed by immersion into Solution II at a temperature of about 15°C. The agar coated potatoes were allowed in Solution II for about 15 minutes. After draining in a colander, 4 peeled potatoes were placed in semi-permeable plastic bag (175 x 190 mm). All plastic packages were heat sealed using a manual sealer (Venus Model VH400). An additional treatment (T1) which acted as a control was prepared by dipping the peeled potatoes in water. All samples were stored at 4±0.5°C.

Treatment effectiveness was evaluated by measuring colour changes at the peeled surface of treated samples and control during storage. To measure colour objectively, the CIELAB's "*L*" (light-dark), "*a*" (red-green) and "*b*" (yellow-blue) for randomly selected surface areas were measured using a Minolta Chroma meter, Model CR300 with a 8 mm specimen port. To evaluate the change in colour, hue angle was also calculated from the tristimulus data ("a" and "b"). Hue angle values of 0°, 90°, 180° and 270 indicate red, yellow, green, and blue, respectively. Hue angle values close to 90° indicate more browning. Generally, a 7° (degrees) reduction in hue angle corresponds to the end of acceptable shelf-life.

A subjective visual evaluation described in Table 3.5 of section 3.3 was also conducted to assess the visual acceptability of fresh peeled potatoes. Visual and objective assessments were conducted using 3 replicate packages.

Table 3.9 - Treatments for whole peeled potatoes prepared using coatings based on agar-agar

Treatment	Solution I (coating)		Solution II		
	Agar@ (%)	Sodium Alginate* (%)	Ascorbic Acid (%)	Citric Acid (%)	Calcium Chloride (%)
T1 (Control)	-	-	-	-	-
T2 (no coat)	-	-	2	0.5	1.0
T3	1.0	-	2	0.5	1.0
T4	2.0	-	2	0.5	1.0
T5	3.0	-	2	0.5	1.0
T6	1.0	0.5	2	0.5	1.0
T7	2%	0.5	2	0.5	1.0
T8	2%	1.0	2	0.5	1.0

@Appendix D

3.9 Preservation of Steam Peeled Potatoes

The object of this experiment was to determine the effectiveness of the novel combination of vegetable gum coating and anti-browning agents in preserving the appearance of steam peeled potatoes.

Approximately 40 kg steam-peeled Russet Burbank potatoes were taken from a commercial processing plant. The potatoes were steam peeled for 15 - 20 seconds with steam at about 220 - 230 psi (204°C). Steam peeled *Russet Burbank* potatoes from the same batch were immediately immersed in cold water inside barrier plastic bags and transported to the testing area which took about 2 hours. Before testing, steam-peeled potatoes were divided into 3 lots corresponding to the treatments shown in Table 3.10. The vegetable gum (coating) and anti-browning agents were applied in two stages as described in section 3.3.

Calcium chloride was added in the solution of ascorbic acid and citric acid in treatment T_2 because calcium chloride may contribute in preventing discolouration in steam peeled potatoes. The type of discolouration commonly found on heat treated potatoes is a black discolouration commonly called "after cooking darkening". The rate of darkening on heated potatoes is generally faster than conventional enzymatic browning found in mechanically peeled potatoes.

After draining in a colander, 4 peeled potatoes were placed in semi-permeable polyethylene blend plastic bag. All plastic packages were heat sealed using a manual sealer (Venus Model VH400). There were 4 replications per treatment. All samples were stored at 4±0.5°C.

Table 3.10 - Treatments used for steam peeled potatoes

Treatment	Anti-browning Solution			Sodium Alginate Coating (%)
	Ascorbic Acid (%)	Citric Acid (%)	Calcium Chloride (%)	
T1: Control	-	-	-	-
T2: Antibrowning solution	2.0	0.5	1.5	-
T3: Coat & T2	2.0	0.5	1.5	2.8

Appendix D

3.10 Use of Erythorbic Acid as Alternative to Ascorbic Acid

The object of this experiment was to compare the effectiveness of various solutions of anti-browning agents that included erythorbic acid, ascorbic acid and citric acid. Erythorbic acid is a cheaper alternative of ascorbic acid.

Approximately 8 kg of Sebago potatoes each weighing about 150g were peeled using an abrasive peeler (P102 Peeler by Pelatori Polivalenti of Italy). Peeled potatoes were washed using tap water and divided into 5 lots corresponding to the treatments shown in Table 3.11. The vegetable gum (coating) and anti-browning agents were applied in two stages: (1) Solution I contained 2.8% vegetable gum (Appendix D); and (2) Solution II was a combination of anti-browning agents (*e.g.* AB1, AB2, or plain water). All solutions were prepared at room temperature and stored at 4°C overnight. Each peeled potato receiving the vegetable gum coating was immersed into Solution I for about 5 minutes, and allowed to drip for about 20 seconds, followed by immersion into Solution II which resulted in a clear homogenous coat/film over the entire surface of the potatoes. It took about 10-20 minutes to complete the second immersion. After draining in a colander, 4 peeled potatoes were placed in semi-permeable polyethylene blend plastic bag (175 x 190 mm). Preliminary work suggested that this packaging film would produce a useful aerobic equilibrium-modified atmosphere of about 2-10% oxygen. All plastic packages were heat sealed using a manual sealer (Venus Model VH400). An additional treatment (T1) which acted as a control was prepared by dipping the peeled potatoes in water. There were 4 replications per treatment. All samples were stored at 4±0.5°C for as long as 21 days.

Table 3.11 - Treatments for whole peeled potatoes using erythorbic and ascorbic acids

Treatment	AA* (%w/v)	EA* (%w/v)	CA* (%w/v)	CC* (%w/v)	Vegetable Gum
T1: Control					
T2: AB1	2	-	0.5	1.5	-
T3: AB2	-	2	0.5	1.5	-
T4: Gum+T2	2	-	0.5	1.5	2.8@
T5: Gum+T3	-	2	0.5	1.5	2.8@

*AA-Ascorbic acid, EA-Erythorbic acid, CA-citric acid, CC-Calcium chloride in Solution II.
@Vegetable gum was present only in the first dip (Solution I).

Treatment effectiveness was evaluated by measuring colour changes at the peeled surface of treated samples and control during storage. To measure colour objectively, the CIELAB's "*L*" (light-dark), "*a*" (red-green) and "*b*" (yellow-blue) for randomly selected surface areas were measured using a Minolta Chroma meter (Model CR300). To evaluate the degree of browning, hue angle was calculated from the tristimulus data ("a" and "b").

A subjective visual evaluation was also conducted to assess the change in colour during storage. A scoring system described in section 3.3. A colour score of "5" and below was considered unacceptable.

3.11 Validation of the Effectiveness on Other Potato Cultivars

The objective of this study was to evaluate the effectiveness of the developed preservation system on various potato cultivars. In addition with the two (2) main cultivars that studied in this project (i.e. Sebago and Coliban), 8 other cultivars were used to evaluate the new preservation system: *Denali, Kipfler, Spunta, Toolangi Delight, Patroness, Russet Burbank, Desiree*, and *Nicola*. All the samples in this study were about 2 months old in relatively good condition. All samples were sourced from the same grower in order to minimise the effects of production practices and other growing conditions.

Potatoes were hand-peeled with a sharp knife and then, temporarily stored in water for about 10 minutes. Peeled potatoes of the same cultivar were divided into 2 lots for the following treatments: (1) "Coated" - samples coated with combinations of alginate and anti-browning agents, (2) Control - samples dipped in water.

Coated samples were prepared and packaged as described in section 3.3. Each peeled potato was immersed into Solution I (2.8% vegetable gum - Appendix D) for about 1-5 minutes, allowed to drip, followed by immersion into Solution II which resulted in a clear homogenous coat over the surface of the potatoes. After draining excess solution, 4 coated tubers were placed in a semi-permeable plastic bag (200 x 240mm). All plastic bag were heat sealed prior to storage at 8 ± 0.5°C.

Control samples were dipped in water for about 2 minutes. After draining excess water, 4 tubers were placed in plastic bags and heat sealed. Samples were placed at 4 ± 0.5°.

3.12 Microbiological Challenge Testing of Pre-Peeled Potatoes

Previous work has shown that fresh peeled potatoes in edible coating containing food grade anti-browning compounds and packed in semi-permeable film have a shelf life of 4 weeks at 1°C and 14 days at 8°C, at which time yeasts exceed $10^7/cm^2$. Since pH elevates during storage, a challenge was conducted with aciduric bacteria. The objectives of this study were to challenge the developed preservation system with aciduric bacteria and to improve this system by the incorporation of an organic preservative (potassium sorbate) in the edible coating.

Fresh *Sebago* potatoes were knife peeled and rinsed in tap water (1 L) containing 72 h cultures of *Lactobacillus sake, Bacillus polymyxa* and *Clostridium pasteurianum* grown in appropriate broths. Peeled potatoes were then divided into 3 groups: first group was prepared using the original preservation system by dipping in a natural edible coating solution followed by anti-browning solution (Appendic D), second group was prepared similar to the previous with additional organic acid incorporated in the coating and anti-browning solutions (Appendix D), and the third group was not coated to act as the control batch. Each group was packaged in semi-permeable bags (95mm x 190mm) of known gas transmission rates and stored at 4°C. Package headspace gas composition was measured using an electronic gas analyser equipped with an infrared CO_2 and a zirconia oxygen sensors. Surface pH of peeled potatoes was measured with a flat electrode.

For microbiological analyses, samples were taken by the surface excision method (AS1766.3.1 - 1979). Further analysis were performed as follows:

Yeasts and Moulds - Oxytetracycline Glucose Yeast Extract Agar (AS1766.2.2 - 1980)

Lactobacilli - Rogosa Agar, 30°C, 48h, Anaerobic

Bacillus polymyxa - Polymyxin Pyruvate Egg Yolk Mannitol Bromothymol Blue Agar (AS1766.2.6 - 1991)

Sulphite Reducing Clostridia - Differential Reinforced Clostridial Broth (MPN) 30°C, 48h, Anaerobic

3.13 Preservation of Frech Fries by Vacuum and Modified Atmosphere Packaging

Results of preliminary studies conducted using *Russet Burbank* potatoes indicate that the use of edible coating on French Fries is not very effective due to the sharp edges and the large surface area. Due to this, the focus of the French Fries studies were concentrated on using "invisible" gas packaging technology supplemented by the use of food grade antibrowning agents.

Table 3.12 gives a summary of the treatments used in this study which include the use of gas flushing technique, vacuum packaging, and blanching solely or combination with the use of antibrowning solutions. Calcium chlorine was not incorporated in the antibrowning solution because it was found in the preliminary study that the presence of calcium chloride increased the firmness of the fries making them less crunchy and more "rubbery".

Table 3.12. Summary of treatments for French fries

Treatment	Dipping solution*	Blanching	Packaging
MA4	4%AA,1%CA,1%SAPP	None	40%CO_2/3%O_2
MA10	10%AA,1%CA,1%SAPP	None	40%CO_2/3%O_2
MAB	4%AA,1%CA,1%SAPP	90°C/6 min	70%CO_2/30%N_2
VAC	Water	None	Vacuum
Control	Water	None	Heat sealed in air

*AA-ascorbic acid, CA-citric acid, SAPP-sodium acid pyrophospahte

All dipping treatments were conducted for a period of 1 minute followed by a 5 minute draining period. Samples were then placed in a permeable polyethylene pouch and gas flushed to produce an initial gas composition of 40% CO_2/3% O_2. MAB samples were blanched at 90°C for 6 minutes and then dipped in an antibrowning solution based on 4% ascorbic acid (Table 3.12).

Vacuum packaging of water-dipped samples were conducted using a Webomatic chamber type machine (Model E50G) with vacuum set at -1bar. Cryovac standard barrier bags were used for vacuum packaging.

4.0 RESULTS AND DISCUSSION

4.1 Preliminary Study on Peeled Potato

4.1.1 Preliminary vacuum packaging of peeled potato

The objective of this preliminary trial was to assess the potential of 2 commercially available sulphite-free antibrowning mixtures reported in the literature.

All treatments including water-dipped samples stored at 1.5°C did not develop any significant change in colour as indicated by Minolta *L*, *a* and *b* values and calculated hue angle values. However, the total aerobic counts reached dangerous levels (10^6 cfu/cm^2) in samples dipped in water (control) and Treatment A (solution A: ascorbic acid, citric acid, calcium chloride and SAPP). The presence of potassium sorbate in Treatment B (solution B) could be responsible in reducing the level of aerobic counts on the 14th and 21st day of storage (Table 4.1).

All samples opened on the 14th and 21st day of storage were sensorily unacceptable because of obvious softening and off-odours most probably due to anaerobic fermentation of the fresh potatoes (Table 4.1, 4.2).

The results of this preliminary study indicate that vacuum packaging in conjunction with the use of selected antibrowning agents and preservatives is an effective tool in inhibiting browning in peeled potatoes. However, there exist a great concern in relation to the creation of anaerobic condition in the package which could be conducive to the growth of pathogenic organisms and anaerobic fermentation. The results of this preliminary indicate that vacuum packaged potatoes are highly vulnerable to fermentation resulting in the production of significant levels of off-odours (Table 4.1, 4.2). In summary, vacuum packaging does not offer a great potential in maintaining the quality and safety of fresh peeled potatoes under refrigerated conditions especially for retail distribution where temperature abuse (>4°C) is expected to be common.

Table 4.1 Microbial counts of vacuum packaged potatoes stored for 14 days at 1.5°C

Treatment	SPC (cfu/cm^2)	Yeast (cfu/cm^2)	Mould (cfu/cm^2)	Sensory Observations
Solution A	108,500	<5	<5	Slight off-odours
Solution B	4,100	<5	<5	Slight off-odours
Control	1,008,000	<5	<5	Slight off-odours

Table 4.2 Microbial counts of vacuum packaged potatoes stored for 21 days at 1.5°C

Treatment	SPC (cfu/cm^2)	Yeast (cfu/cm^2)	Mould (cfu/cm^2)	Sensory Observations
Solution A	3,100,000	<5	<5	Strong off-odour
Solution B	340,000	<5	<5	Strong off-odours
Control	2,460,000	<5	<5	Strong off-odours

4.1.2 Preliminary modified atmosphere packaging (MAP) trial

The objective of this preliminary study was to assess the potential of modified atmosphere packaging (MAP) in preserving the quality of fresh peeled potatoes stored at 4 °C.

Table 4.3 gives a summary of results of visual observation on gas-packaged samples with or without preliminary treatment with an ascorbic acid-based solution. The preliminary results indicate that gas packaging (also called "active" MAP) in conjunction with the use of semi-permeable film may not be an effective method of controlling enzymatic browning in pre-peeled potatoes.

Visual inspection of the samples on the 14th day of storage indicated that there was no significant difference between the "control" (dipped in water and packaged in air) and treated samples GW (dipped in water and packaged in gas), and GA (dipped in ascorbic acid and gas packaged). This could be due to the inability of the semi-permeable film to maintain high levels of carbon dioxide that would prevent enzymatic browning. As indicated by Table 4.4, the level of carbon dioxide declined from 40% to 16% within 24 hours after packaging.

In summary, gas packaging using semi-permeable films, solely or in combination with the use of antibrowning agents offer little potential in controlling enzymatic browning of fresh peeled potatoes.

Table 4.3 Results of visual and odour assessment of gas packaged samples

Treatment	Visual Assessment Day 0	Visual Assessment Day 14
GA	Acceptable (10/10)	Very brown (5/10)
GW	Acceptable (10/10)	Very brown (5/10)
Control	Acceptable (10/10)	Very brown (4/10)

Table 4.4 Changes in package headspace composition of peeled potatoes stored at 4°C

Storage period (days)	Carbon Dioxide (%)	Oxygen (%)
0	40.0 +2.0	3.0 ±0.4
1	16.5 +1.0	3.1+0.5
14	4.9 ±0.4	4.9 ±0.4

4.2 Comparison of Vacuum and Gas Packaging

This study was conducted to evaluate the effects of selected combinations of anti-browning agents, blanching, vacuum and gas packaging on the microbiological quality, colour changes (*i.e.* brown discolouration), and other factors affecting the acceptability of peeled whole potatoes.

4.2.1 Effects on surface discolouration

Fig. 4.1 shows the changes in hue angle of pre-peeled potato tubers prepared and packaged using various treatments specified in Table 3.3.

Based on the changes of hue angle values during storage, all treatments based on vacuum and gas packaging were able to delay the formation of brown discolouration on the surface of the peeled potatoes (Fig. 4.1). In contrast, control or water dipped samples exhibited a rapid decline in hue angle readings during storage. A reduction of 10° was recorded in control samples within 7 days in comparison to only about 2° in gas packaged samples. Greatest inhibition in brown pigment formation was found in vacuum packaged treatments (VA, VS, BA, BS). However aerobic conditions found in these treatments produced off-odours within 7 days at 4°C.

Blanching with or without antibrowning solution increased the whiteness of the potatoes as evidenced by their initial higher hue angle values compared to other treatments (Fig. 4.1). Blanched samples (BA, BS) showed a slow decline in hue angle values but remained visual acceptable even after 14 days at 4°C. Samples prepared by any of the blanching technique exhibited 2 major disadvantages: (i) tubers appeared "cooked" on the surface exhibiting soft texture and very white appearance, and (ii) samples browns rapidly upon exposure to air with the core section browning faster than the blanched surface.

In all cases, dipping in antibrowning solution seemed to be unnecessary in terms of the changes in colour as indicated by the hue angle. This could be due to the ability of vacuum and gas packaging to prevent enzymatic reaction. The inhibition by vacuum packaging is based on the elimination of oxygen which is a substrate in enzymatic reaction. However, vacuum creates anaerobic conditions conducive for pathogenic organisms and fermentation. The use of antioxidants and/or acidulants may still be required in lowering the surface pH of the potatoes in order to reduce microbiological risks.

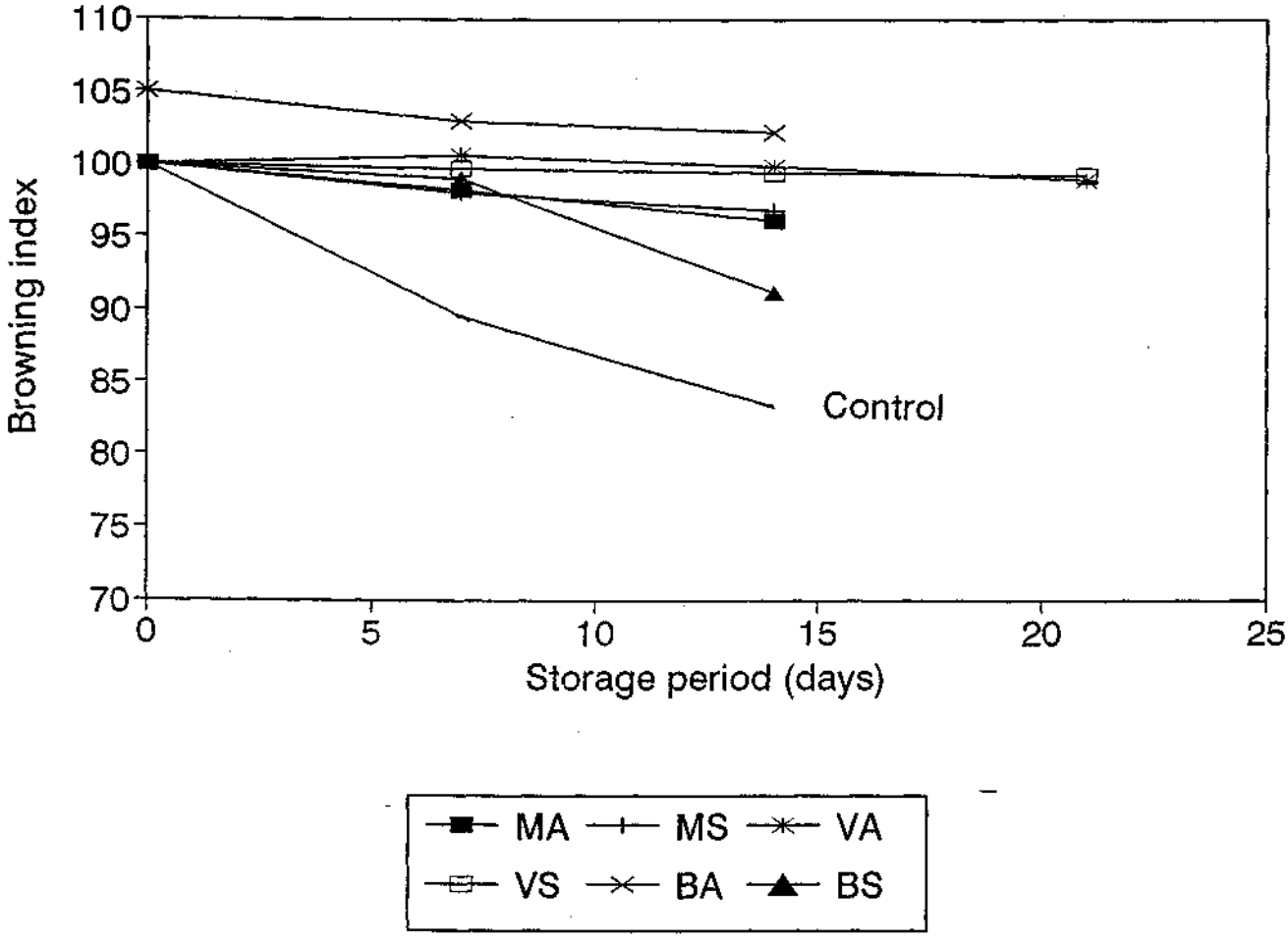

Fig 4.1 Changes in browning index during storage of peeled potatoes

The prevention of enzymatic browning by gas packaging is based on a possible direct inhibition of carbon dioxide against enzymatic reactions. However, the presence of low levels of oxygen (about 3%) and the use of permeable packaging material resulted in a relatively short period of inhibition. Inhibition of browning was significant only until 7 days which is equivalent to the time that carbon dioxide level is more than 5% in the package headspace. The use of barrier films was not tried because this would create very high levels of carbon dioxide (>20%) and very low levels due to the consumption of oxygen and subsequent production of carbon dioxide by the tubers and associated microorganisms. Based on visual observation, both gas packaged treatments (MA, MS) were found to be visually acceptable up to 9 days due to the formation of white discolouration followed by enzymatic browning and surface dehydration. The degree of browning could have been obscured by the white surface discolouration commonly associated with lignin formation which is a by-product of plant tissue wound healing.

A very interesting phenomenon was observed in samples dipped in the antibrowning solution. Although the overall decline in hue angle showed a similar decline in both treatments (MA, MS), visual observation on tubers dipped in antibrowning solution (MS) indicated a consistent inhibition of browning on the bottom side of the package. This indicated that the antibrowning solution is effective in controlling browning in potatoes provided a significant amount of this solution can be maintained on the entire surface of the tubers. Maintenance of antibrowning solution on the surface of the peeled potatoes were achieved by the use of edible coatings as described in section 3.3.

4.2.2 Microbiological effects

All treatments exhibited a general increase in microbial load especially the total aerobic count during storage (Table 4.5). At day 0, a significant reduction in total aerobic count was observed in blanched treatments compared to unheated samples. Greatest inhibition in total aerobic count occurred in treatment BS which were blanched, dipped in antibrowning solution, and vacuum packaged. Although the results of microbiological tests were very encouraging in treatments that were blanched, it is unlikely that this method could be adapted because this procedure produced soft cooked tubers. The shelf life of surface blanched potatoes was less than a week (*i.e.* 5-6 days) because of the development of fermented odours which could be due to anaerobic respiration. Blanched tubers are only blanched on the surface with about 5 mm depth, therefore most of the inner section are still living and such section could respire anaerobically resulting in rapid fermentation.

The results of this study indicate that treatments based on blanching and vacuum packaging would be limited in shelf-life by the development of fermented off-odours.

Table 4.5 Summary of microbiological results of peeled potatoes stored at 4°C

Treatment	Storage period (days)	Surface pH	Yeast Count (cfu/cm^2)	Mould Count	Total aerobic count	Enterobac -teriaceae	Starch Agar Count
VA	**0**	4.6	<5	46	17,140	184	30
VS	**0**	4.5	6	26	2,813	23	29
BA	**0**	5.8	<5	3	156	<5	13
BS	**0**	3.9	<5	<5	23	<5	16
MA	**0**	6.0	9	31	4,640	183	25
MS	**0**	4.0	4	11	2,928	28	14
VA	**7**	5.0	5	6	10,113	2,254	2,625
VS	**7**	4.5	5	30	849	10	22
BA	**7**	5.8	<5	3	149	15	39
BS	**7**	4.5	3	<5	18	<5	<5
MA	**7**	6.3	50	8	615	40	70
MS	**7**	5.4	121	26	3,834	21	41
VA	**14**	5.8	4	13	27,625	13,620	5,075
VS	**14**	5.0	<5	48	4,537	164	33
BA	**14**	5.8	<5	5	296	26	37
BS	**14**	NT	NT	NT	NT	NT	NT
MA	**14**	6.3	720	1,150	25,950	3,208	2,268
MS	**14**	6.5	1,463	3,113	4,538	18	78

NT: Not tested

4.3 Effects of Coating and Levels of Antibrowning Agents on Shelf-life of Peeled Potatoes

The objective of this experiment was to determine the range of concentrations of selected anti-browning agents and the effectiveness of alginate based gel coating in inhibiting enzymatic browning in peeled whole potatoes.

4.3.1 Relationship between visual score and various indices of colour

Correlation coefficient values between various indices of browning are given in Table 4.6. Visual scores were found to correlate in the following order of decreasing magnitude: hue angle > *a* value > *b* value > chroma > whiteness index > *L* value. The highest correlation coefficient of 0.90 was obtained between visual score and hue angle indicating that hue angle values can be used as an objective indicator of the degree of browning in peeled potatoes. Hue angle value is dependent on both *a* and *b* values (*i.e.* hue angle = $\tan^{-1}\{b/a\}$). Interestingly, *L* value and whiteness index which are commonly reported as indices of colour changes and browning were found to be inadequate indicators of browning. A graphical relationship between visual score and hue angle values is shown in Fig. 4.2.

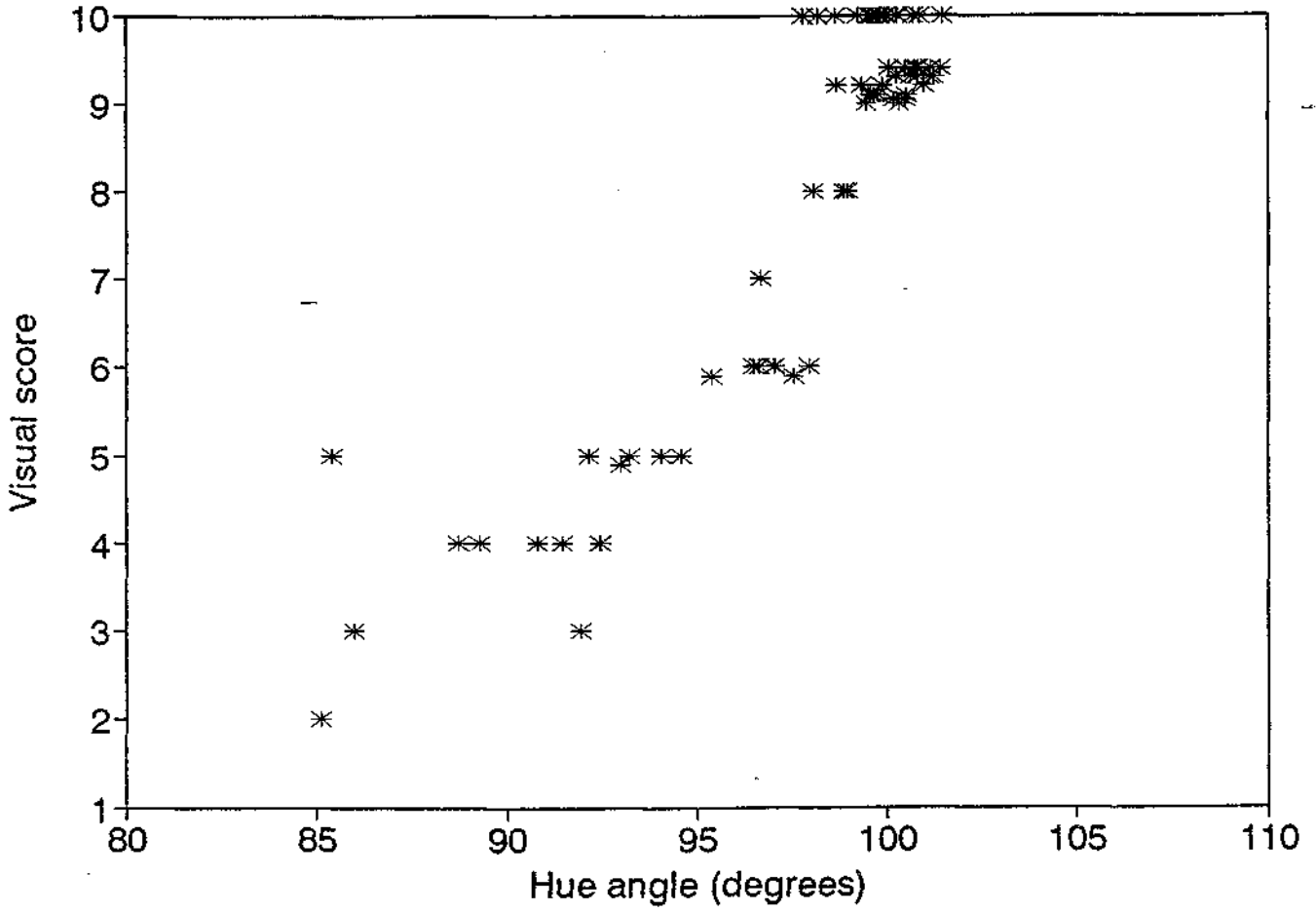

Fig 4.2 Graphical relationship between visual score and hue angle values

Table 4.6. Correlation coefficient of various indices of browning with visual score

Colour indices	Visual	"L"	"a"	"b"	Hue	Chroma	W.I.
Visual	1.00						
"L"	-0.18	1.00					
"a"	**-0.85**	-0.29	1.00				
"b"	**-0.81**	-0.38	0.78	1.00			
Hue	**0.90**	0.32	-0.98	-0.86	1.00		
Chroma	**-0.80**	-0.38	0.77	1.00	-0.85	1.00	-0.57
W.I.	0.35	0.98	-0.45	-0.58	0.50	-0.57	1.00

Visual: visual score

Hue: hue angle = tan-1 (b/a)

W.I.: whiteness index = 100 $\{(100 - L)^2 + a^2 + b^2\}^{1/2}$

Chroma = $(a^2 + b^2)^{1/2}$

4.3.2 Mathematical modeling of browning reaction during storage

The results of visual scores and hue angle measurements based on CIE-*LAB* colour assessments during storage of peeled potatoes are shown in Figs. 4.3 and 4.4.

A first order kinetics similar to the Arrhenius equation was found to adequately represent the reduction in hue angle of peeled potato tubers during refrigerated storage. Table 4.7 gives the reaction "k" values for each treatments. Treatments T1 and T2 did not change in hue angle during the storage period considered in this study, therefore they do not have a k value. Based on statistical analysis, the treatments can be group into 4: very slow or no reaction (T1, T2, T4), slow reaction (T3), medium reaction (T5, T6, T7) and fastest reaction (T8 or control). Treatment T3 gave a lower effectiveness compared to T4 probably due to the higher pH which resulted with the addition of SAPP which is generally a good buffering agent. The results of this study indicate that treatment T4 (*i.e.* alginate gel coating with 2% ascorbic acid, 0.5% citric acid) is the most "cost-effective" treatment evaluated in this study for extending the shelf-life of peeled potatoes foe a period of 22 days at 4°C.

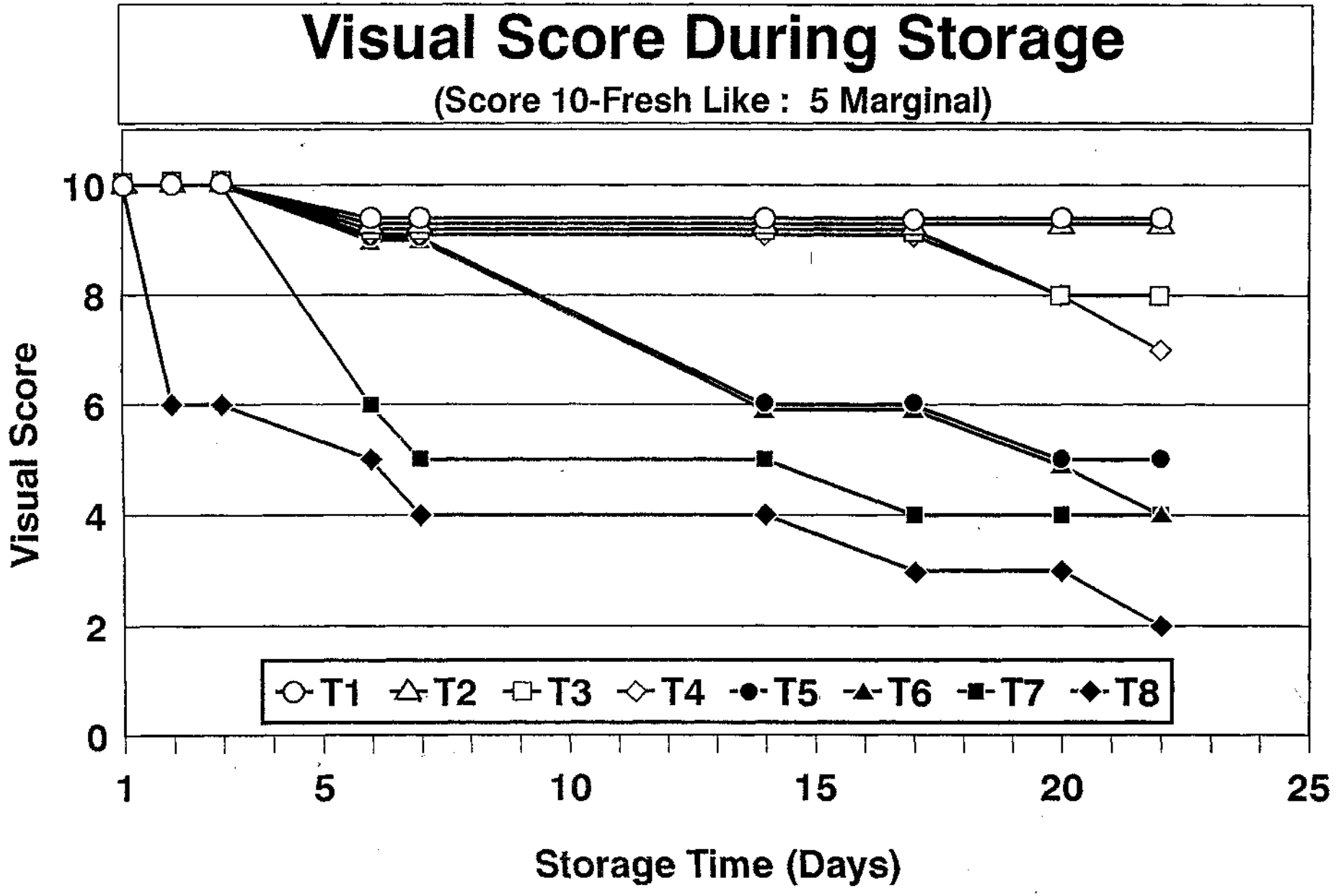

Fig. 4.3 Changes in visual scores during storage of peeled potatoes

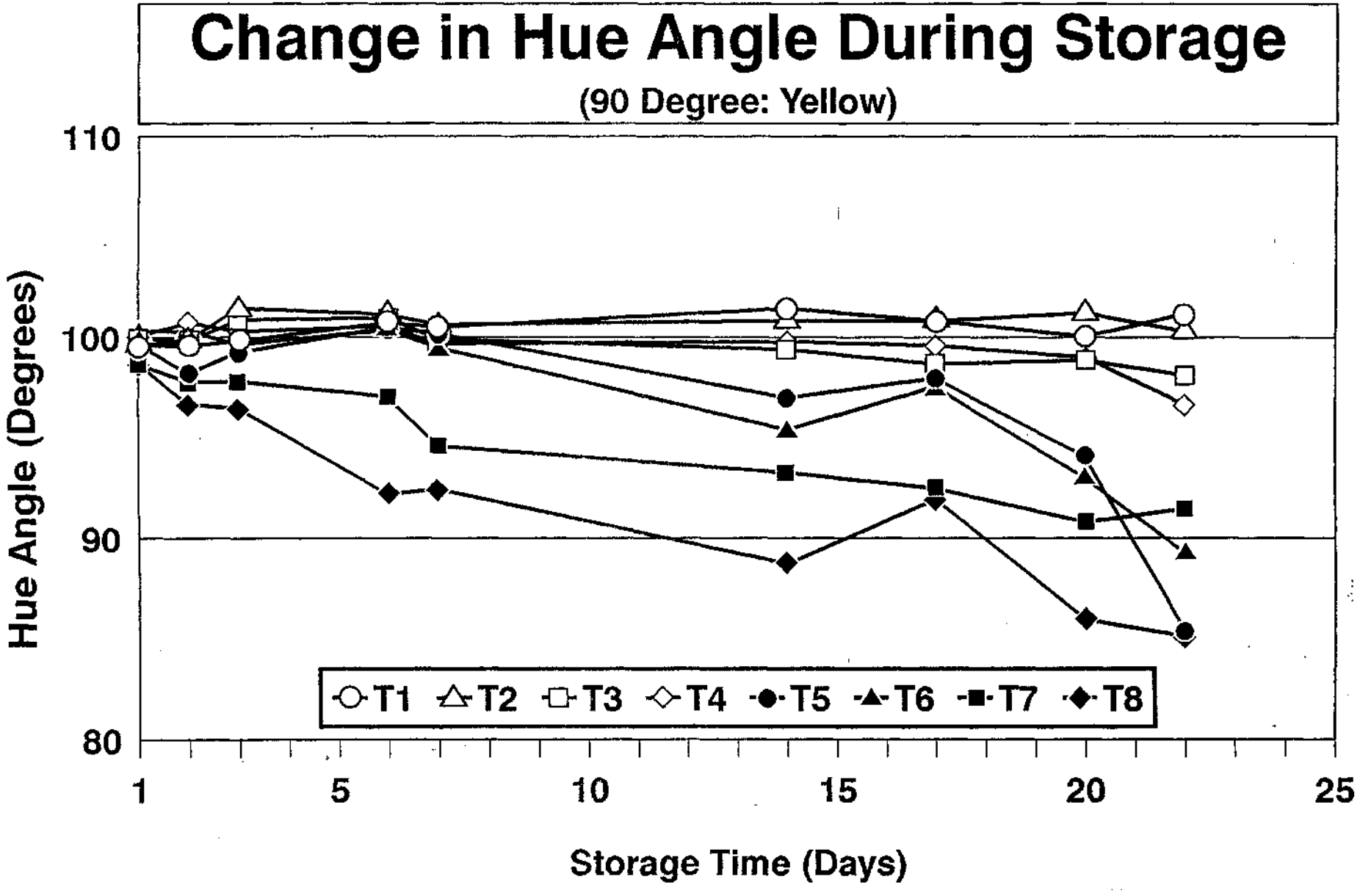

Fig. 4.4 Changes in hue angle values during storage of peeled potatoes

Table 4.7 Summary of reaction kinetic values

Treatments	k (slope)	Correlation coefficient (R)	Grouping*
T1	0	-	a
T2	0	-	a
T3	-0.00058	0.71	b
T4	-0.00070	0.67	a
T5	-0.00350	0.71	c
T6	-0.00360	0.87	c
T7	-0.00380	0.97	c
T8	-0.00660	0.92	d

**t - test (0.05)*

Model: HR = exp (k t)

HR = Hue ratio

$= Hue_{(t)} / Hue_{(initial)}$

k = reaction rate

t = storage period (days)

4.3.3 Shelf life of peeled potatoes

Based on visual score, it is possible to store peeled potatoes at 4°C for up to 22 days with an acceptable appearance (Fig. 4.3). In contrast, control samples dipped in water were found to be acceptable only up to the 3rd day of storage with a visual score of 6 (limit of acceptability). Treatments T1, T2, T3 and T4 were found to give similar degree of browning inhibition. However, T4 would require the least amount of anti-browning agents amongst these four potential treatments to achieve similar levels of effectiveness.

As discussed previously, hue angle calculated from a and b values was found to have a high degree of correlation with visual score (r = 0.90). *Sebago* white potatoes used in this study exhibited an initial hue angle of about 100° (Fig. 4.4). A reduction in hue angle indicates browning or yellowing. A hue angle of about 95° corresponds to a visual score of about 6 which is the limit for shelf life acceptance. The trends in hue angle values were similar to visual scores. The hue angle of treatments T1, T2, T3 to T4 did not change significantly even up to 22 days of storage. Table 4.8 gives a summary of shelf-life values based on visual observation and hue angle values.

Table 4.8 Shelf-life of peeled potatoes based on visual and hue angle values

Treatment	Shelf-life (days)	
	Visual score	Hue angle
T1	≥22	≥22
T2	≥22	≥22
T3	≥22	≥22
T4	≥22	≥22
T5	17	17
T6	17	17
T7	7	7
T8 (Control)	3	4

The results of this study was also able to demonstrate that coating alone can inhibit browning up to 5 days compared to 1 to 2 days with the control samples. Comparison of T6 with T5, T4 with T3, and T2 with T1 indicate that the levels of SAPP (sodium acid pyrophosphate, a chelating agent) did not contribute any noticeable beneficial effects in inhibiting enzymatic browning.

It is hypothesised that the possible mechanisms involved in the inhibition of enzymatic browning on the surface of the potatoes include the direct effects of ascorbic acid and calcium chloride on PPO enzymes, inactivation by lowering pH on the cut surface, and binding of the PPO enzymes by the polysaccharide coating.

In summary, treatment T4 required the least concentration of anti-browning agents that could inhibit browning in peeled potatoes stored at 4±0.5 °C for up to 22 days. This extension in shelf life is very significant compared to a shelf life extension of 7 days reported by O'Beirne and Ballantyne (1987) for potato strips dipped in 10% ascorbic acid solution, packaged under aerobic atmosphere and stored at 5°C.

4.3.4 The model preservation system for peeled potatoes

Fig. 4.5 is a diagrammatic illustration of the developed preservation system for peeled potatoes which excludes the use of sulphur dioxide and vacuum packaging. The layers on top of the package represents the various preservation methods or "hurdles to spoilage" giving additive and/or synergistic effects that enabled the extension in product's shelf life.

The first two (2) layers immediately above the package illustrated in Fig. 4.5 are not preservation methods but essential steps in product preparation and processing: (i) proper postharvest handling, and (ii) good manufacturing practices. The main preservation methods in this patented preservation system are as follows: low temperature storage, edible coating, antioxidant, acidulant, and modified atmosphere packaging.

Refrigeration. Refrigeration is a mandatory preservation method for all minimally processed vegetables in order to slow down deteriorative physiological disorders and microbial spoilage, and reduce the risk from pathogens. Storage temperature will affect both the shelf life and the type of spoilage limiting the product shelf life. Longest shelf life is generally achievable at temperature close to the freezing point of the product (*i.e.* -1.5 to 0°C).

Antioxidant, acidulant, and edible coating. The use of antioxidant is a part of the preservation system in order to prevent enzymatic browning by reducing orthoquinones to colourless diphenols. An acidulant was added in order to reduce the pH of the coating. The role of acidulant is to maintain the surface pH of the potatoes below that necessary for optimal catalytic activity ($\leq$4.0). Fresh potatoes have a pH of 5.4 to 5.8. An edible coating carries both the antioxidant and acidulant on the exposed surface of the potato tubers.

Modified atmosphere packaging (MAP). The package designed for peeled potatoes was made of inexpensive permeable films that can maintain aerobic conditions. Equilibrium atmospheres of about 5-10 % oxygen and 5-10 % carbon dioxide was consistently developed in these modified atmosphere packages at 1 to 8°C storage conditions.

Results of subsequent tests conducted on whole peeled potatoes of various cultivars and different peeling methods were able to confirm the effectiveness of the developed preservation system against enzymatic browning and microbial spoilage.

A photograph showing 2 possible packaging formats for whole peeled potatoes processed using the developed preservation system is shown in Fig. 4.6.

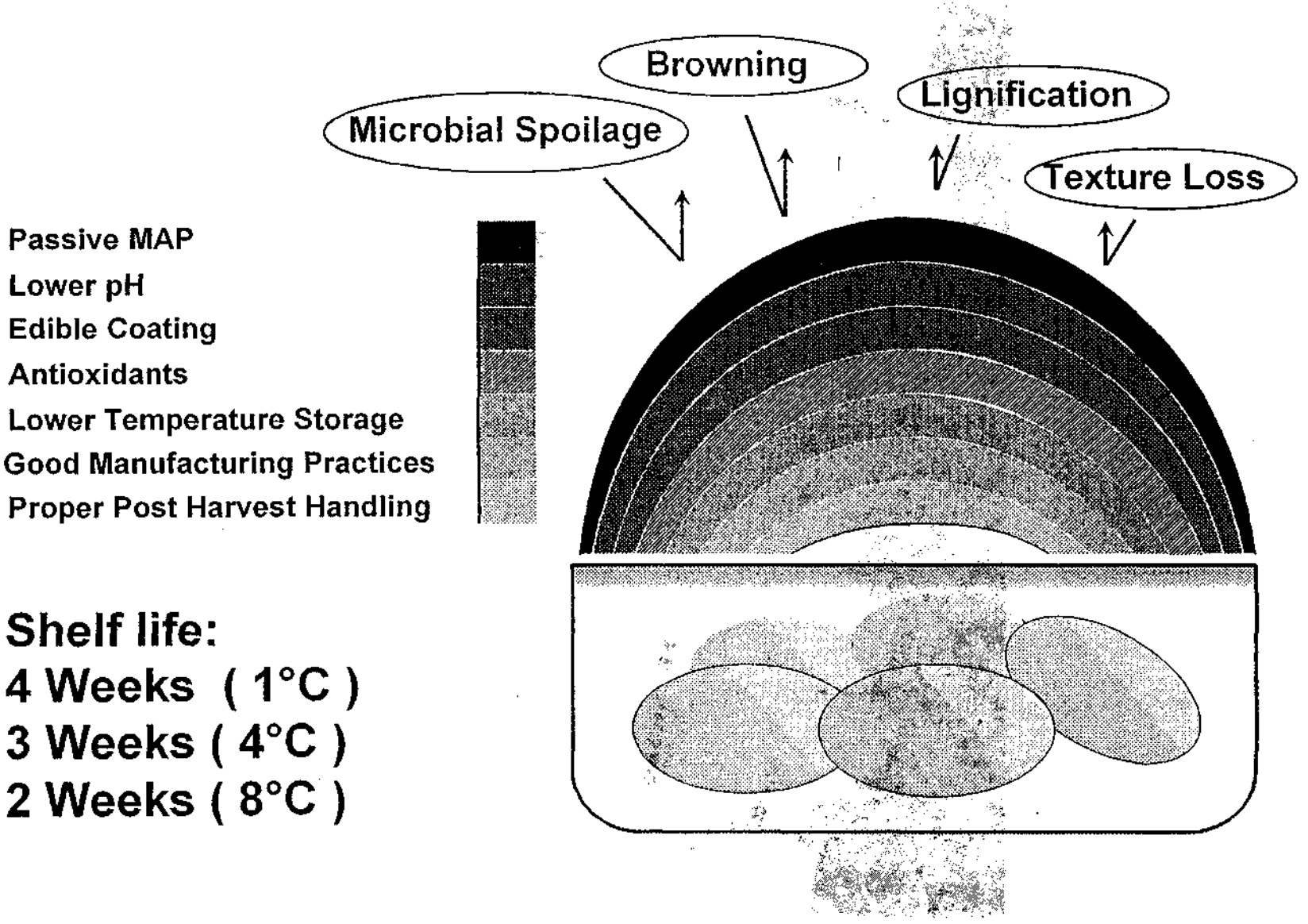

Fig. 4.5 A representation of the model preservation system for peeled potatoes

Fig. 6 Model packaging formats for whole peeled potatoes (left: food service format, right: retail packaging)

4.4 Shelf-life of Coated Samples Under Various Packaging and Storage Conditions

The main objective of this study was to determine the shelf-life of peeled potatoes prepared and packaged using the novel process described previously in section 4.3 that combined coating, anti-browning agents, and semi-permeable packaging. The effects of gas packaging on product quality were also evaluated in comparison with a passive generation of modified atmosphere. A summary of treatments used in this study was given in Table 3.6 (section 3.4).

4.4.1 Colour changes

Storage at 1°C. Tables 4.9 gives a summary of visual evaluation and hue angle values of peeled potatoes stored at 1°C. A graphical representation of the changes in hue angle of the potatoes during storage is shown in Fig. 4.7.

The results of visual observation indicate that whole peeled potatoes that were prepared and packaged using the developed system (1A and 1G) and stored at 1°C were visually acceptable even after 28 days. No off-odour was detected in all treated samples indicating the absence of anaerobic respiration. In comparison, control samples (1C) that were dipped in water exhibited browning and white lignin formation within 2 days of storage at 1°C.

Computed hue angle values support the results of visual observations. Hue angle values of treated samples (1A and 1G) did not change significantly even after 28 days of storage at 1°C (Fig. 4.7). In contrast hue angle values of the control sample decreased from 100 to 97° in just 4 days of storage at 1°C. The results of both visual and hue angle value indicate that gas flush packaging did not give any significant advantage compared to a passive method of MA generation (1A). This could be due to the inability of CO_2 to remain in the package for a long period of time. CO_2 concentration in gas flushed packages decline from an initial 30% to less than 10% within 24hours.

Fig. 4.8 shows the photograph of whole peeled potatoes after 4 weeks storage at 1°C.

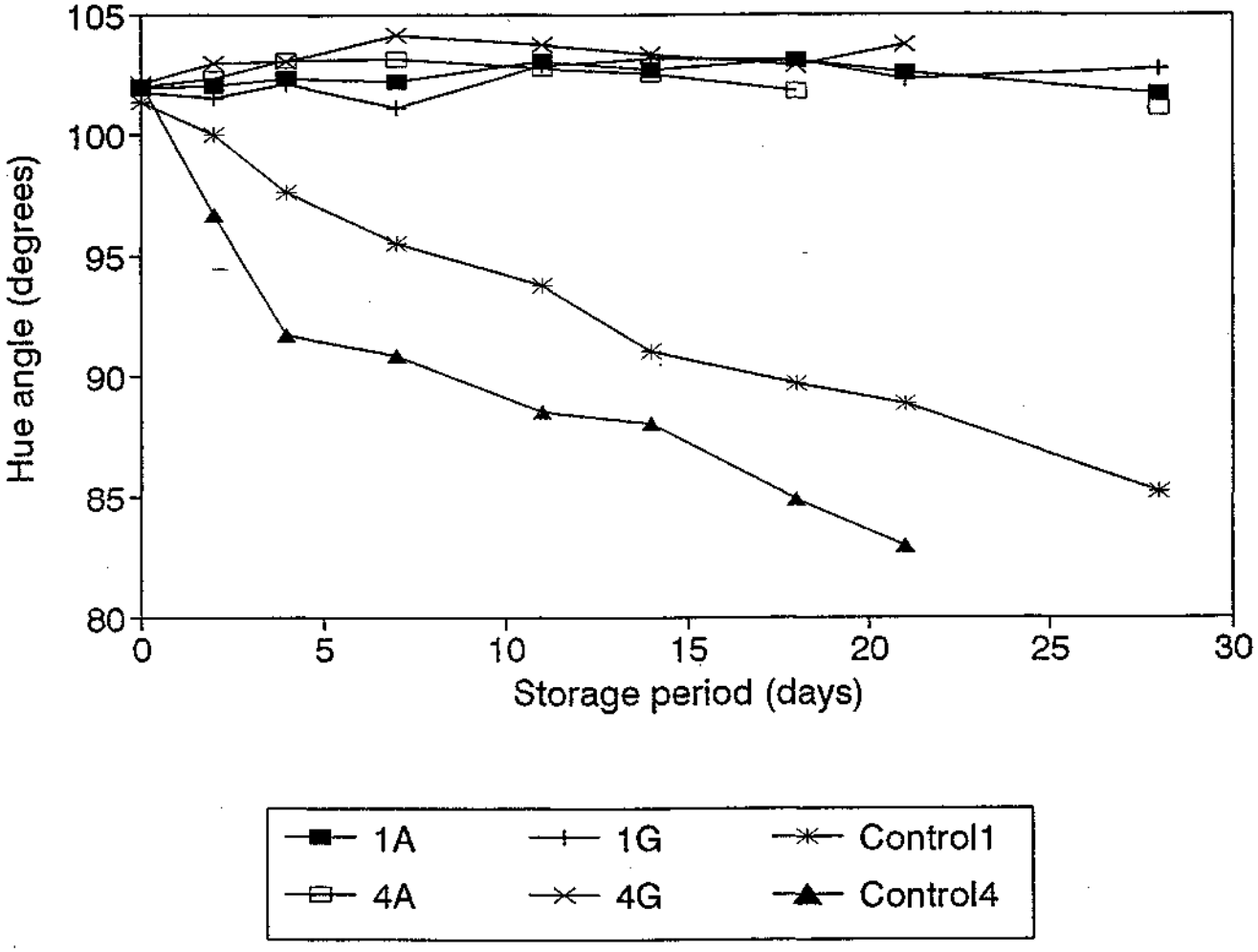

Fig. 4.7 Changes in hue angle of peeled potatoes stored at 1°C

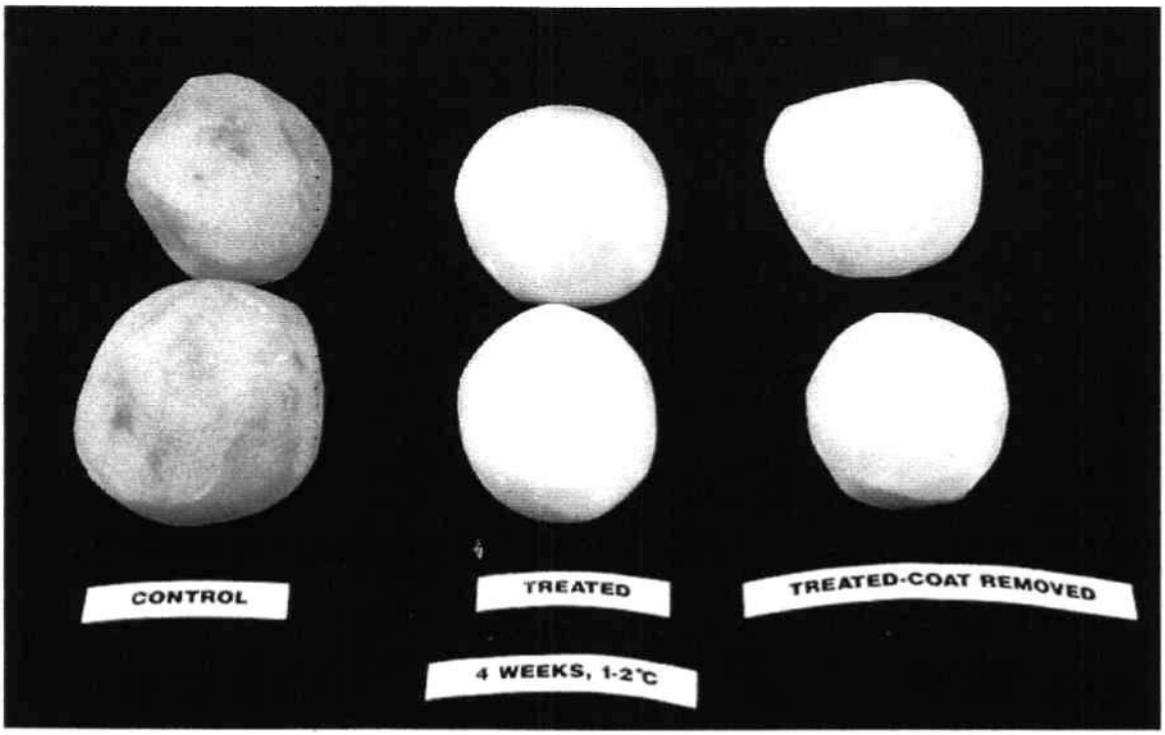

Fig. 4.8 Uncoated and coated potatoes after 4 weeks at 1°C (left: uncoated sample, middle: coated sample 1A, right: coated 1A sample with coating removed)

Table 4.9 Results of colour assessments of peeled potatoes stored at 1°C

Treatment	Storage Days	Hue Angle	Visual Score	Comments
1C	0	101.4	10	Acceptable
1C	7	97.6	5	Browned, white lignin
1C	14	91.0	4	Extreme browning
1C	21	88.8	4	Extreme browning
1C	28	85.2	4	Extreme browning
1A	0	101.9	10	Acceptable
1A	7	102.2	9	Acceptable
1A	14	102.7	8	Acceptable
1A	21	102.5	8	Acceptable
1A	28	101.7	8	Acceptable
1G	0	101.7	10	Acceptable
1G	7	101.1	9	Acceptable
1G	14	103.1	8	Acceptable
1G	21	102.3	8	Acceptable
1G	28	102.8	8	Acceptable

Storage at 4 °C. The trends observed for samples stored at 4°C were similar to those samples stored at 1°C (Fig. 4.6 and Table 4.10). All treated samples did not exhibit browning during the entire duration of the storage. However, visual signs of mould and yeast growth were observed in treated samples after 28 days of storage at 4°C. This suggest that the maximum shelf life attainable in peeled potatoes is 28 days at 4°C. This is a very significant extension in shelf life because the control untreated samples displayed a shelf life of only 3 days because of the development of enzymatic browning and white lignin formation on the surface of the potatoes.

Table 4.10 Results of colour assessments of peeled potatoes stored at 4°C

Treatment	Storage Days	Hue Angle	Visual Score	Comments
4C	0	102.0	10	Acceptable
4C	7	91.7	5	Browned, white lignin
4C	14	88.5	4	Extreme browning
4C	21	84.8	4	Extreme browning
4C	28	83.0	4	Extreme browning
4A	0	102.0	10	Acceptable
4A	7	103.0	9	Acceptable
4A	14	102.8	8	Acceptable
4A	21	101.8	7	Acceptable
4A	28	101.1	5	Mould, yeasts growth
4G	0	102.0	10	Acceptable
4G	7	103.0	9	Acceptable
4G	14	103.0	8	Acceptable
4G	21	102.8	8	Acceptable
4G	28	103.7	5	Mould, yeasts growth

4.4.2 Microbiology

Storage at 1 ℃. All treated samples (1A and 1G) were found to contain acceptable levels of microbial loads even after 28 days of storage at 1°C (Table 4.11). Except for yeasts and standard plate count (SPC), there was no significant increase in microbial loads during the entire duration of the experiment. The inhibition in microbial growth could be due to the lowering of pH on the surface of the potatoes which was about 2.7 immediately after packaging (Table 4.12). In addition, both ascorbic acid and citric acids were reported in the literature to exhibit antimicrobial action in model system of peeled potatoes (Giannuzzi and Zaritzky, 1993). The pH of Solution II at the start of the trial was about 2.0 (Table 4.12). Yeasts which could survive low pH (≥1.5), increased from 4 cfu/cm^2 initially to 1.1 x 10^5 after 28 days. This yeasts count is considered acceptable compared to the limit of 4 x 10^6 cfu/cm^2 prescribed by the French Standards regulating the fresh-cut or minimally processed vegetable industry (Anonymous, 1988).

Table 4.11 Microbial counts of peeled potatoes stored at 1°C

Treatment	Storage Days	Yeast (cfu/cm^2)	Moulds (cfu/cm^2)	Aerobic Count (cfu/cm^2)	Anaerobic Count (cfu/cm^2)
1A	0	4	4	8	3
1A	7	3	3	22	3
1A	14	214	4	143	3
1A	21	4.9 x 10^3	3	328	328
1A	28	6.5 x 10^4	48	4.0 x 10^3	8
1G	0	4	4	8	3
1G	7	3	4	8	3
1G	14	11	8	10	3
1G	21	205	3	39	3
1G	28	4.2 x 10^4	43	4.2 x 10^3	1.0 x 10^3

Table 4.12 Composition of package headspace and pH samples stored at 1°C

Treatment	Storage Days	Atmosphere (%)		pH	
		O_2	CO_2	Solution	Surface
1C	0	21.0	0.0	-	-
1C	7	7.6	3.2	-	-
1C	14	9.7	2.6	-	-
1C	21	4.2	3.2	-	-
1C	28	6.6	4.7	-	-
1A	0	21.0	0.0	2.0	2.8
1A	7	10.0	2.7	3.2	2.7
1A	14	11.0	1.8	3.4	3.6
1A	21	6.1	2.2	3.6	3.4
1A	28	5.9	3.4	3.7	3.7
1G	0	4.8	35.0	2.0	2.7
1G	7	10.0	3.7	3.2	2.4
1G	14	12.0	1.6	3.4	3.5
1G	21	7.0	2.0	3.5	3.2
1G	28	6.0	3.4	3.6	3.6

Storage at 4°C. All the microbial counts from treated potato samples stored at 4°C for 28 days were within acceptable limits. The changes in microbial counts were similar to those treated samples stored at 1°C. However, the magnitude of increase is slightly higher in yeasts and aerobic plate counts (Table 4.13). The packaging format used in this study developed an equilibrium atmosphere of 4-5%O_2 and 3.5-5%CO_2 (Table 4.14). These modified atmosphere conditions are expected to allow the natural respiration of the potatoes but at a reduced level.

Table 4.13 Summary of microbiological results on peeled potatoes stored at 4°

Treatment	Storage Days	Yeast (cfu/cm^2)	Moulds (cfu/cm^2)	Aerobic Count (cfu/cm^2)	Anaerobic Count (cfu/cm^2)
4A	0	4	3	15	3
4A	7	3	4	13	3
4A	14	3.1×10^3	3	1.3×10^3	70
4A	21	4.8×10^4	4	9.9×10^3	374
4A	28	4.0×10^5	53	1.2×10^5	52
4G	0	4	3	10	3
4G	7	4	3	18	3
4G	14	186	3	61	4
4G	21	3.3×10^4	3	2.0×10^4	3
4G	28	7.5×10^4	10	9.6×10^4	3

Table 4.14 Composition of package headspace and pH samples stored at 1°C

Treatment	Storage Days	Atmosphere (%)		pH	
		O_2	CO_2	Solution	Surface
4C	0	21.0	0.0	-	-
4C	7	8.1	3.2	-	-
4C	14	5.5	3.8	-	-
4C	21	3.9	3.0	-	-
4C	28	4.3	3.5	-	-
4A	0	21.0	0.0	2.0	2.7
4A	7	10.8	3.0	3.1	2.8
4A	14	9.7	2.8	3.5	3.1
4A	21	6.2	2.9	3.7	3.6
4A	28	5.1	5.1	4.1	3.8
4G	0	6.0	31.0	2.0	2.7
4G	7	7.5	4.0	2.7	3.2
4G	14	10.1	2.6	3.4	-
4G	21	7.5	2.0	3.7	3.5
4G	28	4.3	4.9	3.9	3.8

4.4.3 Texture

The treatments and storage period used in this example, all had no effect on firmness of raw potatoes as measured by a compression test employed in this study. The firmness values given in Tables 4.15 and 4.16 relate to the maximum force encountered during a 3mm penetration of a 8mm diameter probe on the surface of the fresh potatoes. The treated potatoes (1A, 1G, 4A, 4G) did not exhibit any significant change in surface firmness during the 28 day period used in this storage trial (Tables 4.15 and 4.16). Control samples were not monitored because they became unacceptable within 2 days.

Table 4.15 Summary of firmness analysis of peeled stored at 1°C

Treatment	Storage Days	Firmness (N)	
		Mean	Deviation
1A	0	40.5	6.3
1A	7	45.1	6.1
1A	14	56.0	4.1
1A	21	41.8	6.9
1A	28	40.3	8.9
1G	0	40.3	8.9
1G	7	41.8	3.1
1G	14	53.9	5.4
1G	21	39.0	5.9
1G	28	42.9	4.0

Table 4.16 Summary of firmness analysis of peeled stored at 4°C

Treatment	Storage Days	Firmness (N)	
		Mean	Deviation
4A	0	40.5	6.3
4A	7	44.3	3.5
4A	14	40.0	3.0
4A	21	41.3	3.9
4A	28	41.2	3.5
4G	0	40.3	6.3
4G	7	40.5	3.1
4G	14	40.4	5.3
4G	21	40.5	6.3
4G	28	42.5	5.5

4.5 Comparison Between the Developed Preservation System and Sulphur Dioxide Treatment

The objective of this study was to compare the novel process of combining coating and anti-browning agents with the traditional use of sodium metabisulphite solution in preserving the fresh appearance of peeled potatoes stored at 8°C. This storage temperature was selected in order to simulate temperature conditions during display periods in supermarkets in Australia.

Table 4.17 shows the results of visual scoring and hue angle measurements, and Table 4.18 summarises the microbiological results of peeled potatoes stored at 8°C for 21 days.

Table 4.17 Results of colour assessment of coated and sulphur dioxide treated potatoes at 8°C

Treatment	Storage Period (days)	Hue angle (degree)	Visual Score	Comments
Control	0	99.1	10	Acceptable
Control	3	91.8	5	Brown spots
Control	6	88.5	4	Extreme browning
Control	10	86.9	4	Extreme browning
Control	14	83.6	4	Extreme browning
	21	-	-	Not tested
Sulphited	0	99.2	10	Acceptable
Sulphited	3	99.0	8	Slight off-odour
Sulphited	6	98.8	6	Soft, loss of vacuum
Sulphited	10	99.2	5	Very soft texture
Sulphited	14	99.2	4	Extremely soft
Sulphited	21	-	-	Not tested
Coated	0	99.3	10	Acceptable
Coated	3	99.8	9	Acceptable
Coated	6	99.8	8	Acceptable
Coated	10	100.8	8	Acceptable
Coated	14	99.2	8	Acceptable
Coated	21	-	5	Mould and yeast growth

Table 4.18 Microbiological results of coated and sulphur dioxide treated potatoes at 8°C

Treatment	Storage Period (days)	Yeast (cfu/cm^2)	Moulds (cfu/cm^2)	Lactobacilli (cfu/cm^2)	Clostridia (cfu/cm^2)
Control	0	<50	50	<50	<4
Control	3	<50	<50	-	-
Control	6	140	<50	-	-
Control	10	-	-	-	-
Control	14	-	-	-	-
Sulphited	0	<50	<50	<50	<4
Sulphited	3	<50	<50	-	-
Sulphited	6	50	<50	-	-
Sulphited	10	150	100	-	-
Sulphited	14	<50	<50	1.8×10^7	<4
Coated	0	<50	<50	<50	<4
Coated	3	<50	<50	-	-
Coated	6	60	<50	-	-
Coated	10	3.6×10^3	<50	-	-
Coated	14	5.7×10^4	<50	<50	<4

As the information in Tables 4.17 and 4.18 show, it is possible to store peeled potatoes for at least 14 days at 8±0.5°C without using sodium metabisulphite. After 14 days of storage at 8°C, coated potatoes looked and smelled like freshly peeled potatoes. There was no significant colour change in coated potatoes as indicated by hue angle values (Table 4.17). The shelf life of coated potatoes was terminated when yeasts and mould growth became visible on the 21st day of storage (Table 4.18). Yeasts were the most dominant organisms present in coated potatoes. As expected, it was *Lactobacilli* that dominated the microflora of vacuum packaged sulfited potatoes. *Lactobacilli* is known to grow under anaerobic conditions common in vacuum packaged products (Table 4.18).

In sulfited-vacuum packaged potatoes, the shelf life was limited to 6 to 10 days because of the development of off-odour, loss of vacuum, and considerable softening of the potato surface. On the 10th day of storage, sulfited potatoes were very soft and slimy, and therefore unacceptable to consumers. Similar undesirable changes in potato strips and whole peeled potatoes have been reported in the literature (Francis and Amla, 1961; Furlong, 1961; Giannuzzi et al. 1988). Surface softening and off-odour development could be due to sulfur dioxide as reported Francis and Amla (1961). However, the mechanism causing this softening is still unknown. Softening could also be due to anaerobic fermentation and/or pectinolytic activity of *Lactobacilli* which is the most dominant organism in vacuum packaged potatoes.

4.6 Synergistic and Additive Effects of Various Coating Components

The object of this experiment was to determine the individual and possible synergistic effects of a selected mixture of anti-browning agents and sodium alginate gel coating in inhibiting enzymatic browning in abrasively-peeled raw potatoes.

Table 4.19 shows the changes in hue angle, "*L*" values, and visual score during a 3 week period at 4°C. Both hue angle and "*L*" decrease during storage as a direct result of enzymatic browning on peeled potatoes prepared by treatments T1, T2, and T3. The novel combination of vegetable gum coating and mixture of anti-browning agents (T4) did not result in any significant reduction in both *"L"* and hue angle values indicating maintenance of the original colour of the potatoes. Previous tests have shown that hue angle is the "best" indicator of enzymatic browning on the surface of peeled potatoes. Generally, a 7° reduction in the original value of hue angle is considered unacceptable for the abrasively-peeled *Sebago* potatoes used in this study.

Table 4.20 gives a summary of shelf-life of peeled potatoes based on visual observations and Fig. 4.9. Results from this table show that dipping of abrasively-peeled potatoes in a solution of 2% ascorbic acid and 0.5% citric acid (T2) did not result in any extension in shelf-life compared to those samples dipped in water (T1, control treatment). Mixtures of ascorbic acid and citric acid are generally recommended to prevent enzymatic browning in cut or damaged fruit and vegetables.

The application of sodium alginate coating on peeled potatoes which is not a common industry practice, was able to give an additional 3 days shelf-life compared with control samples. This result indicate that coating alone can be a potential tool in extending the shelf-life of peeled potatoes. The potential of vegetable gum coating was best illustrated by treatment T4 which combined the gum coating and the anti-browning mixture. In this novel approach, enzymatic browning was inhibited and shelf-life of peeled potatoes was extended up to 21 days. This result suggest synergism between the use of coating and the mixture of ant-browning agents since adding the shelf-life values by the use of coating alone (T3) and anti-browning mixture (T2) would give only 11 days. The extension of shelf-life up to 21 days instead of 11 days strongly suggest synergism between the use of coating and mixtures of anti-browning agents.

Table 4.19 Colour assessment of abrasively-peeled potatoes prepared under various conditions

Treatment	Storage days	Hue Angle	"L" value	Visual score	Comments
T1:	0	99.7	74.5	10	Acceptable
	7	91.7	71.7	4	Unacceptable
Control	14	88.9	70.4	4	Unacceptable
	21	NT*	NT*	NT*	-
T2:	0	99.7	74.9	10	Acceptable
	7	86.9	70.8	4	Unacceptable
Anti-	14	84.1	70.3	4	Unacceptable
browning	21	NT	NT	NT	-
solution					
T3:	0	96.3	63.6	10	Acceptable
	7	91.2	64.6	6	Marginally
Coat only	14	87.0	64.9	4	acceptable
	21	NT	NT	NT	Unacceptable
					-
T4:	0	100.8	67.6	10	Acceptable
	7	103.1	68.8	10	Acceptable
T2 & T3	14	104.7	69.9	9	Acceptable
	21	104.7	70.8	8	Acceptable

NT - not tested

Table 4.20 Summary of shelf-life values of peeled potatoes prepared by dipping in anti-browning solution, coating, and their combination

Treatment	Shelf-life (days)
T1: Control	4
T2: Anti-browning solution	4
T3: Coat only	7
T4: T2 & T3	21

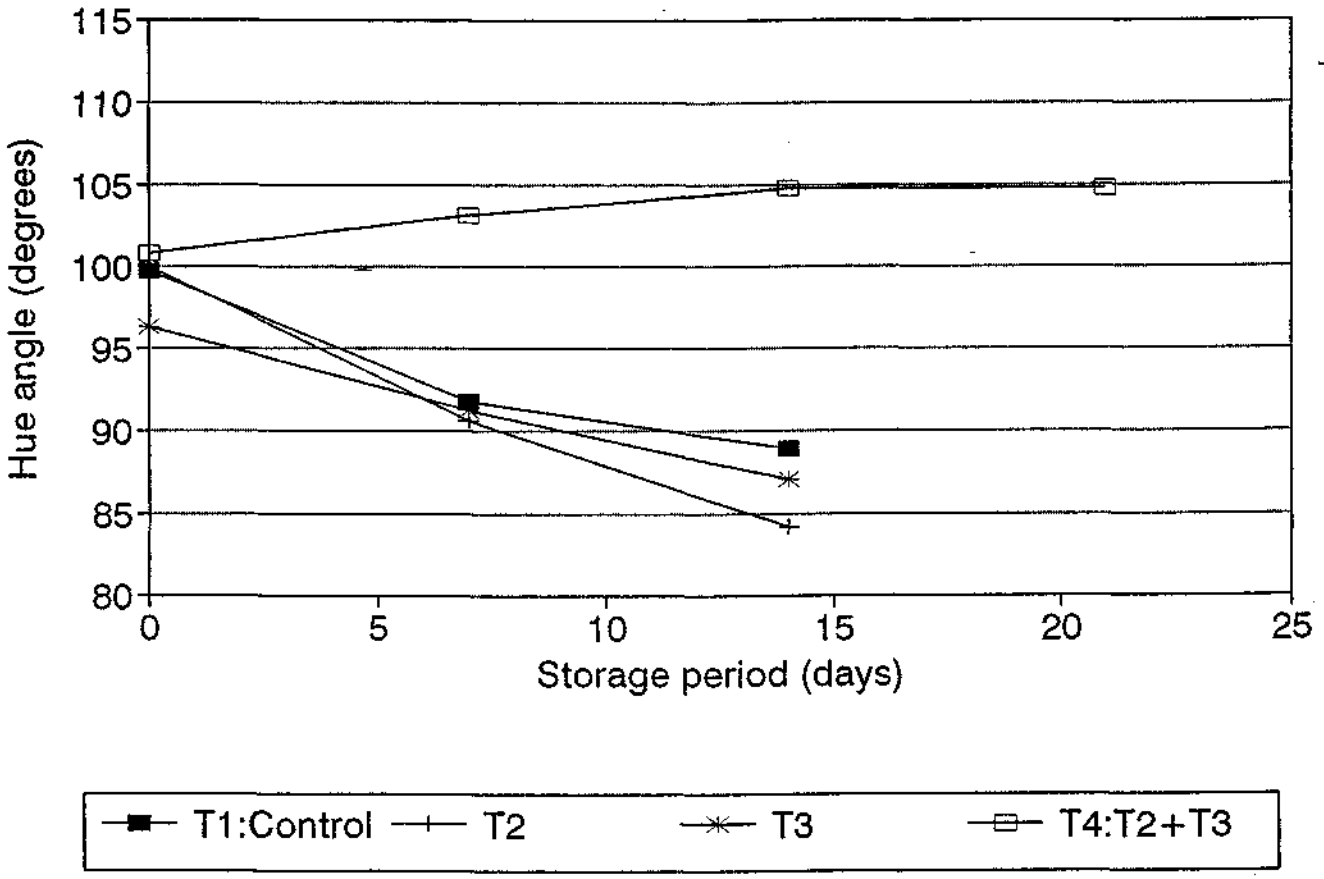

Fig. 4.9 Changes in hue angle of peeled potatoes due to various coating ingredients

4.7 Determination of Effective Levels of Anti-browning Agents and Coatings

The objective of this study was to evaluate the effects of the amount of the coating and antibrowning agents on surface browning of peeled potatoes.

The results of the test are shown in Tables 10.21 and 10.22. As the information in Tables 10.21 and 10.22 shows, it is possible to extend the shelf-life of abrasive-peeled potatoes up to about 21 days at 4°C using treatments of low viscosity coatings T3 and T4, medium viscosity coatings T6 and T7, and high viscosity coatings T9, and T10 (refer to Table 3.8 for details). This extension in shelf-life is more than 500% compared to the shelf-life of control or water-dipped samples that were packaged and stored under similar conditions. Amongst these treatments, T3 was found to give a 21 day shelf-life requiring low levels of sodium alginate coating and anti-browning agents. The weight gained by the use of treatment T3 was measured to be only 4.7% (weight of coating per weight of peeled potatoes) which was calculated to be equivalent to 0.14% kg sodium alginate/kg peeled potatoes (Table 10.22). This very low level of usage of sodium alginate is not expected to exceed the recommended ADI which was reported to be about 50 mg/kg body weight. Likewise, the low levels of ascorbic acid (2%) and citric (0.5%) in T_3 would be economically acceptable to processors.

The results of this test suggest that the most significant factor affecting shelf-life was the level of anti-browning agents (Solution II). The effects of the amount or thickness of coating (expressed here as weight gained) was not very significant under the conditions used in this study. There was no additional shelf-life gained by the use of "thicker" coatings because after 21 days at 4°C, shelf-life was limited by the appearance of yeast growth not by enzymatic browning. The use of "thicker" coatings and high levels of anti-browning agents may have some applications if the growth of yeasts can be inhibited by the use of food approved organic preservatives such as benzoic acid or potassium sorbate.

Finally, the choice of coating formulation would largely depend on the target "buyers/users" of peeled potatoes. Some people may prefer less visible coating which can be prepared using treatments T3 or T4, while others may prefer "easy-to-peel" thicker coating prepared by treatments T6, T7, T9, and T10.

Table 10.21 Result of colour assessment of peeled potatoes stored at 4°C

Treatment	Storage days	Hue Angle	"L" value	Visual score	Comments
T1: Control	0	98.5	70.1	10	Acceptable
	4		67.166	6	Acceptable
	7	82.3	.4	4	Unacceptable
	14	78.6	68.2	3	Unacceptable
	21	-	-	-	NT@
	26	-	-	-	NT@
T2:	0	95.7	72.6	10	Acceptable
	4	97.9	73.4	9	Acceptable
	7	92.8	70.7	6	Acceptable
	14	86.6	68.7	5	Unacceptable
	21	-	-	-	Unacceptable
	26	-	-	-	
T3	0	99.8	75.4	10	Acceptable
	4	100.1	74.7	10	Acceptable
	7	100.2	74.3	9	Acceptable
	14	100.2	73.9	8	Acceptable
	21	95.9	71.9	6	Acceptable, slight browning
	26	NT	NT	4	Unacceptable
T4	0	99.1	75.9	10	Acceptable
	4	100.4	78.0	10	Acceptable
	7	102.5	73.9	9	Acceptable
	14	102.7	76.7	9	Acceptable
	21	102.9	75.6	9	Acceptable
	26	-	-	5	Mould & yeast, No browning
T5	0	100.6	72.5	10	Acceptable
	4	98.4	70.7	10	Acceptable
	7	93.2	70.9	8	Acceptable
	14	82.4	65.6	5	Unacceptable
	21	-	-	-	NT@
	26	-	-	-	NT@
T6	0	100.0	71.7	10	Acceptable
	4	100.8	73.5	10	Acceptable
	7	99.5	73.1	9	Acceptable
	14	99.1	72.6	9	Acceptable
	21	90.7	69.9	9	Acceptable
	26	-	-	5	Unacceptable, yeast growth
T7	0	101.3	72.6	10	Acceptable
	4	101.4	74.2	10	Acceptable
	7	101.5	73.1	9	Acceptable
	14	101.9	73.8	9	Acceptable
	21	101.5	74.1	8	Acceptable
	26	-	-	5	Unacceptable, yeast growth
T8	0	100.2	70.3	10	Acceptable
	4	100.2	70.5	10	Acceptable
	7	90.9	69.7	9	Acceptable
	14	81.9	66.5	8	Acceptable
	21	-	-	5	Unacceptable
	26	-	-	-	NT@
T9	0	102.5	62.8	10	Acceptable
	4	98.6	71.3	10	Acceptable
	7	99.3	71.8	9	Acceptable
	14	97.4	71.7	8	Acceptable
	21	90.5	69.6	7	Acceptable
	26	-	67.3	5	Unacceptable, browning
T10	0	99.4	71.8	10	Acceptable
	4	99.9	72.8	10	Acceptable
	7	100.1	73.4	9	Acceptable
	14	99.9	73.1	9	Acceptable
	21	100.9	72.9	8	Acceptable
	26	-	-	5	Mould & yeast growth, no browning

NT - not tested

Table 10.22 Summary of shelf-life values obtained from abrasively-peeled potatoes prepared using various coatings and anti-browning agents

Treatments	% Weight Gained by Coating	Shelf-life (days)
T1 (Control)	-	4
T2	4.7	7
T3	4.7	21
T4	4.7	>21 to < 26
T5	7.1	7
T6	7.1	>21 to <26
T7	7.1	>21 to <26
T8	8.3	7
T9	8.3	>21 to <26
T10	8.3	>21 to <26

4.8 Heat Soluble Coating for Peeled Potatoes

The object of this experiment was to evaluate the effectiveness of vegetable gum coatings based on agar or "agar-agar" solely or in combination with sodium alginate. The use of agar solely or in combination with sodium alginate can produce a "thermo-reversible" coating which can be an advantage for some specialised applications.

Based on the results of Tables 4.23 and 4.24, thermo-reversible agar-based coatings can be an alternative to sodium alginate coatings in extending the shelf-life of peeled potatoes. Results of treatment T4 have shown that the application of 2% agar in conjunction with 2% ascorbic acid, 0.5% citric acid, and 1.0% calcium chloride can extend the shelf-life of raw peeled potatoes against enzymatic browning up to 3 weeks at 4°C. Similar effectiveness can be attained by the application of 3% agar as illustrated by treatment T5. Coatings from T4, and T5 are fully thermo-reversible in boiling water. For a "fully" thermoreversible coating, treatment T4 is recommended.

In cases where extra coating strength is required, the addition of sodium alginate with agar may be necessary. The results of treatments T6, T7, and T8 have shown that blends of agar and sodium alginate offered about the same magnitude of effectiveness as indicated by their shelf-life values (Table 4.24). These blends of agar and alginate coatings (T6, T7, and T8) would normally turn into small "onion-like" fragments during boiling.

In summary, the results of this test suggest that an agar concentration as low as 2% (T4), and a blend of 1% agar with 0.5% alginate (T6) could deliver similar shelf-life values obtained by the use of "pure" sodium alginate coatings. Higher concentration of agar or blends with sodium alginate can also offer the same effectiveness as shown by treatments T4 to T8.

Table 4.23 Summary of visual appearance of raw peeled potatoes coated with agar

Treatment	Storage days	Hue Angle	"L" value	Visual score	Comments
T1: Control	0	94.4	74.5	10	Acceptable
	5	85.5	71.7	4	Unacceptable
	8	82.6	71.2	4	Unacceptable
	16	78.8	69.5	3	Unacceptable
	21	-	-	-	NT
T2:	0	100.9	75.4	10	Acceptable
	5	89.4	70.1	5	Marginally acceptable, browned surface
	8	90.3	72.0	4	Unacceptable
	16	81.2	66.7	-	NT
	21	-	-	-	NT
T3	0	100.5	74.6	10	Acceptable
	5	93.4	72.2	7	Acceptable
	8	95.5	72.8	5	Marginally acceptable
	16	88.8	69.3	4	Unacceptable
	21	82.3	65.6	3	Unacceptable
T4	0	101.3	74.1	10	Acceptable
	5	99.5	71.9	10	Acceptable
	8	99.2	71.9	9	Acceptable
	16	99.9	70.5	7	Acceptable, few brown spots
	21	93.6	69.5	6	Acceptable, slight browning
T5	0	102.1	70.7	10	Acceptable
	5	102.4	69.7	10	Acceptable
	8	99.3	69.8	9	Acceptable
	16	100.2	70.1	8	Acceptable
	21	101.7	69.7	8	Acceptable
T6	0	100.9	73.7	10	Acceptable
	5	99.6	72.6	10	Acceptable
	8	99.5	70.9	9	Acceptable
	16	100.5	72.2	8	Acceptable
	21	101.2	71.9	7	Acceptable, slight browning
T7	0	100.5	71.6	10	Acceptable
	5	100.5	72.2	10	Acceptable
	8	100.1	72.6	9	Acceptable
	16	100.6	73.0	9	Acceptable
	21	95.2	71.4	7	Acceptable, slight browning
T8	0	98.8	68.3	10	Acceptable
	5	98.6	68.0	10	Acceptable
	8	98.6	68.7	9	Acceptable
	16	98.6	68.8	9	Acceptable
	21	97.7	69.2	8	Acceptable

NT - not tested

Table 4.24 Summary of shelf-life values obtained from peeled potatoes treated with agar based coatings

Treatments	Appearance of Coating	Shelf-life (days)
T1 (Control)	Not applicable	1
T2	Not applicable	5
T3	Non-uniform coat/glaze	8
T4	Thin glaze, desirable	21
T5	Thick glaze	21
T6	Weak but uniform coat	21
T7	Thick uniform coat	21
T8	Thick uniform coat	21

4.9 Preservation of Steam Peeled Potatoes

The objective of this study was to determine the effectiveness of the novel preservation system based on the use of vegetable gum coating and permeable packaging in preserving the fresh quality of steam peeled potatoes.

Table 4.25 shows the changes in hue angle, "*L*" values, and visual score reflecting the changes in colour of steam peeled *Russet Burbank* potatoes during a 2 week period at 4°C. A reduction in hue angle and "*L*" values represents an increase in dark discolouration on the surface of the potatoes. Table 4.26 gives a summary of shelf-life values of steam peeled potatoes in this experiment.

Steam peeled potatoes used in this experiment were observed to develop dark discolouration within an hour after exposure to ambient air. The rate and amount of dark discolouration was found to be excessive compared to surface discolouration found in mechanically peeled potatoes. Water-dipped control samples were found to have a shelf-life of less than a day because of excessive surface darkening of steam peeled potatoes. In comparison, dipping steam peeled potatoes treated with a mixture of ascorbic acid, citric acid and calcium chloride (treatment T2) was able to slow down the rate of darkening up to a period of about 3-4 days at 4°C. This shelf life may not be commercially

acceptable because a shelf life of at least 7 days is required in any preservation system to be commercially attractive.

The developed novel preservation system (treatment T3) was found to be very effective in inhibiting darkening of steam peeled potatoes up to a period of 2 weeks (Table 4.26). During a 2 week period, no significant change in colour was observed in coated potatoes as indicated by hue angle values and visual scores. This result confirmed the effectiveness of the developed preservation system based on the use of vegetable coating on commercially steam peeled potatoes. Longer shelf-life may be obtained by the use of coating if potatoes can be treated immediately after steam peeling. In this study, the steam peeled potatoes were temporarily kept under water for about 4 hours prior to the application of the edible coating and packaging.

Fig. 4.10 shows the photographs of untreated (T1) and treated (T3) steam peeled potatoes after 7 and 21 days of storage at 4°C.

Table 4.25 Colour assessment of steam peeled *Russet Burbank* potatoes prepared under various conditions

Treatment	Storage days	Hue Angle	*"L"* value	Visual score	Comments
T1:	0	108.6	71.6	10	Acceptable
	7	85.6	58.8	3	Unacceptable, dark discolouration
Control	14	NT*	NT*	NT*	Unacceptable
T2:	0	108.6	71.6	10	Acceptable
	7	98.9	66.7	4	Unacceptable, dark discolouration
Anti-browning solution	14	NT	NT	NT	Unacceptable
T3:	0	110.8	72.1	10	Acceptable
	7	110.8	72.1	10	Acceptable, no discolouration
Coat + T2	14	108.4	72.3	9	Acceptable, no discolouration

NT - not tested

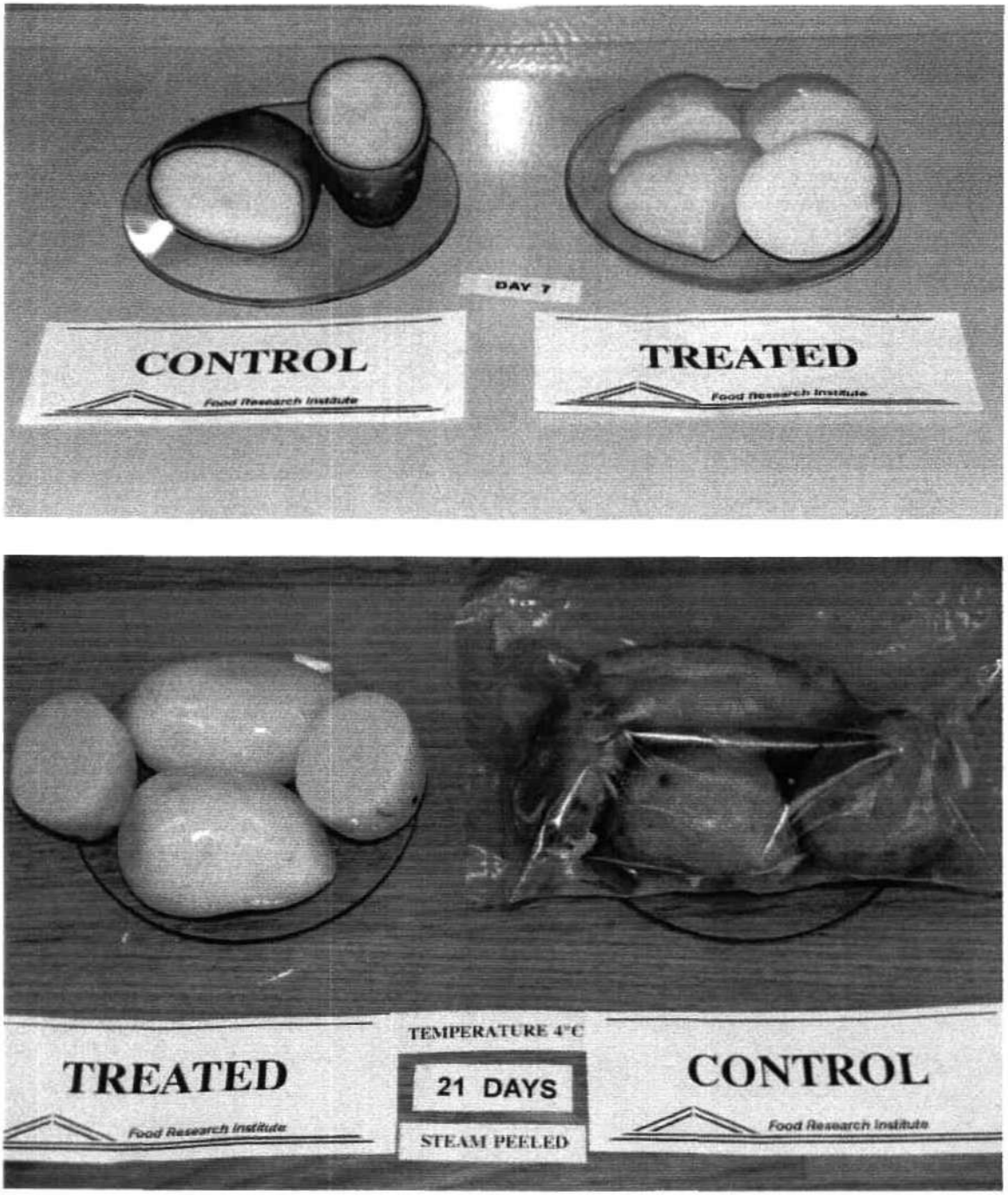

Fig. 4.10 Steam peeled potatoes during storage at 4°C (top-left: control T1 after 7 days; top-right: treated T3 after 7 days; bottom-left: treated T3 after 21 days; bottom-right: control T1 after 21 days)

Table 4.26 - Summary of shelf-life values of steam peeled Russet Burbank potatoes

Treatment	Shelf-life (days)
T1: Control	0
T2: Anti-browning solution	4
T3: Coat & T2	14

4.10 Comparison of Erythorbic with Ascorbic Acid

The object of this experiment was to compare the effectiveness of various solutions of anti-browning agents that included erythorbic acid, ascorbic acid and citric acid. Erythorbic acid was evaluated as an alternative because it is a cheaper compared with ascorbic acid.

Tables 4.27 and 4.28 clearly demonstrate that combination of vegetable gum coating and anti-browning agents (T4 and T5) could significantly inhibit enzymatic browning and extend the shelf-life of peeled potatoes. The use of ascorbic (T2) or erythorbic (T3) based antibrowning solutions without the use of vegetable gum coating was found to be ineffective in preventing surface discolouration due to enzymatic browning. Shelf-life values in Table 4.28 indicate that significant extension of shelf-life can be obtained only if the selected antibrowning agents were combined with the edible coating (T4 and T5). Shelf-life was extended up to 700%, from 3 days up to 21 (treatment T5 compared to treatments T2 or T3). Erythorbic acid was found to be an equivalent efficacy and inexpensive alternative to ascorbic acid (Vitamin C).

In summary, this example was able to demonstrate the synergistic effects of applying anti-browning agents with vegetable gum, thereby prolonging the shelf-life of peeled potatoes up to 21 days compared to 1 day with control samples and 3 days with anti-browning agents only.

A photograph illustrating the effectiveness of combining edible gum coating with ascorbic and erythorbic based antibrowning agents is shown in Fig. 4.11.

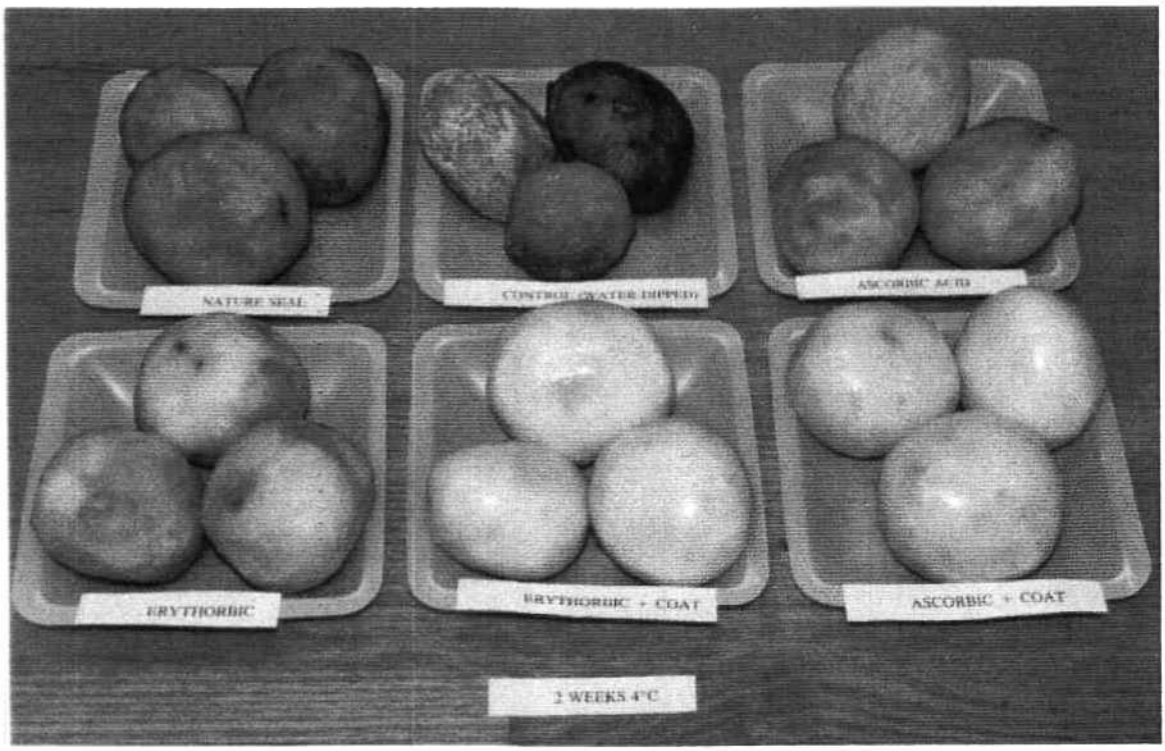

Fig. 4.11 Peeled potatoes after 2 weeks at 4°C (top-left: NatureSeal; top-centre: control T1; top-right: ascorbic acid-no coating T2; bottom-left: erythorbic-no coating T3; bottom-middle: erythorbic with coat T4; bottom-right: ascorbic and coating T5)

Treatment	Storage days	Hue Angle	"L" value	Visual score	Comments
T1: Control	0	100.1	71.6	10	Acceptable
	4	78.5	64.86	4	Unacceptable
	8	74.4	5.9	4	Unacceptable
	14	NT*	NT*	NT*	-
T2: AB1	0	99.7	76.9	10	Acceptable
	4	88.4	72.1	5	Unacceptable
	8	81.7	68.9	4	Unacceptable
	14	NT	NT	4	-
T3: AB2	0	99.7	76.9	10	Acceptable
	4	92.1	74.1	5	Unacceptable
	8	85.1	69.9	4	Unacceptable
	14	NT	NT	NT	-
T4: Gum+T2	0	98.4	70.1	10	Acceptable
	4	99.7	73.7	9	Acceptable
	8	100.2	73.9	8	Acceptable
	14	95.6	73.7	7	Acceptable, slight browning
T5: Gum+T3	0	99.3	70.9	10	Acceptable
	4	101.2	73.9	10	Acceptable
	8	100.0	74.6	9	Acceptable
	14	97.1	72.3	8	Acceptable

*NT - not tested

Table 4.28 Shelf-life of peeled potatoes stored at 4°C

Treatment	Shelf-life (days)
T1: Control	1
T2: AB1	3
T3: AB2	3
T4: Gum + AB1	14
T5: Gum + AB2	21

4.11 Microbiological Challenge Testing on Peeled Potatoes

Results of microbiological analysis indicate that uncoated peeled potatoes did not support the growth of *Clostridium pasteurianum* and *Lactobacillus sake* but spoilt visually within 3-4 days due to enzymatic browning. This is probably due to the presence of oxygen in the package headspace. The initial oxygen composition in the package headspace was 21% and range from 3-10% after a week. The equilibrium oxygen concentration that developed in the package was about 4% O_2 in control samples, and 8% O_2 in both coated samples which did and did not contain an organic preservative (Fig. 4.12). The equilibrium CO_2 concentration in the package headspace was about 3-4 % CO_2 in control samples and 2-4 % CO_2 in both coated samples.

Bacillus polymyxa survived on the uncoated potatoes but did not increase until after 11 days at 4°C. Coated potatoes with or without an organic acid remained visually acceptable up to 29 days of storage. None of the bacteria used in this study survived in coated potatoes. The addition of an organic acid improved the quality of peeled potatoes by inhibiting growth of yeasts up to day 11 and moulds up to day 29 (Figs. 4.13 and 4.14)

The results of this study have demonstrated that both the original and improved (*i.e.* added preservative) preservation systems enabled the extension of shelf life up to 29 days at which point peeled potatoes were still microbiologically ($<10^7/cm^2$) and visually acceptable.

4.12 Preservation of Other Potato Cultivars

The objective of this study was to evaluate the effectiveness of the developed preservation system on various potato cultivars. In addition to the two (2) main cultivars *Sebago* and *Coliban*, 8 other cultivars were also used to evaluate the effectiveness of newly developed preservation system. The additional cultivars studied were: *Denali, Kipfler, Spunta, Toolangi Delight, Patroness, Russet Burbank, Desiree*, and *Nicola*. All the samples used in this study were about 2 months old in relatively good condition. These potato samples were sourced from the same grower in order to minimise the effects of production practices and other growing conditions.

Figs. 4.15, 4.16, and 4.17 show the results of surface colour assessment based on hue angle of 8 selected potato cultivars during a 28 day storage period storage at 4°C. As expected, all the control water dipped samples exhibited a dramatic decline in hue angle values during storage. With the exception of *Spunta* potatoes, all uncoated peeled potatoes were found to be visually unacceptable after a week at 4°C. Amongst the cultivars studied, *Denali* was found to be the most susceptible cultivar to enzymatic browning. The following is the increasing order of susceptibility to enzymatic browning of the 8 cultivars studied: *Spunta* < *Kipfler* ≤ *Toolagi Delight* ≤ *Russet Burbank* ≤ *Nicola* < *Patrones* ≤ *Denali.*

Regardless of cultivar, peeled potatoes coated and packaged using the developed preservation protocol were found to be visually acceptable up to 28 days at 4°C. In comparison, all untreated (control) peeled potatoes were visually unacceptable within 7 days. The shelf life of coated potatoes was terminated when yeasts growth became visible on the 30th day of storage.

The results of the storage trial conducted showed that the developed preservation system effectively prevented the development of enzymatic browning in 8 additional cultivars.

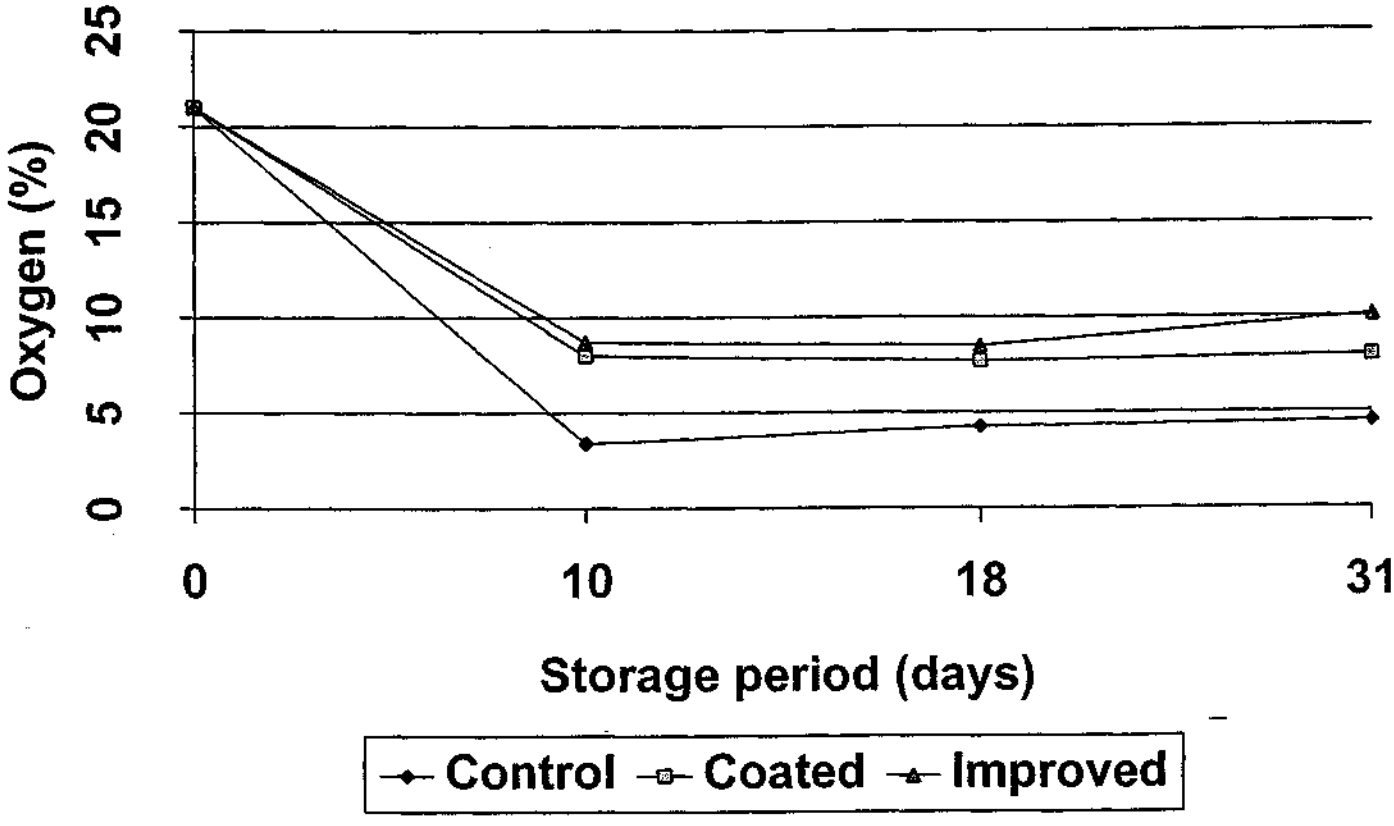

Fig. 4.12 Oxygen concentration in the package headspace of peeled potatoes stored at 4°C

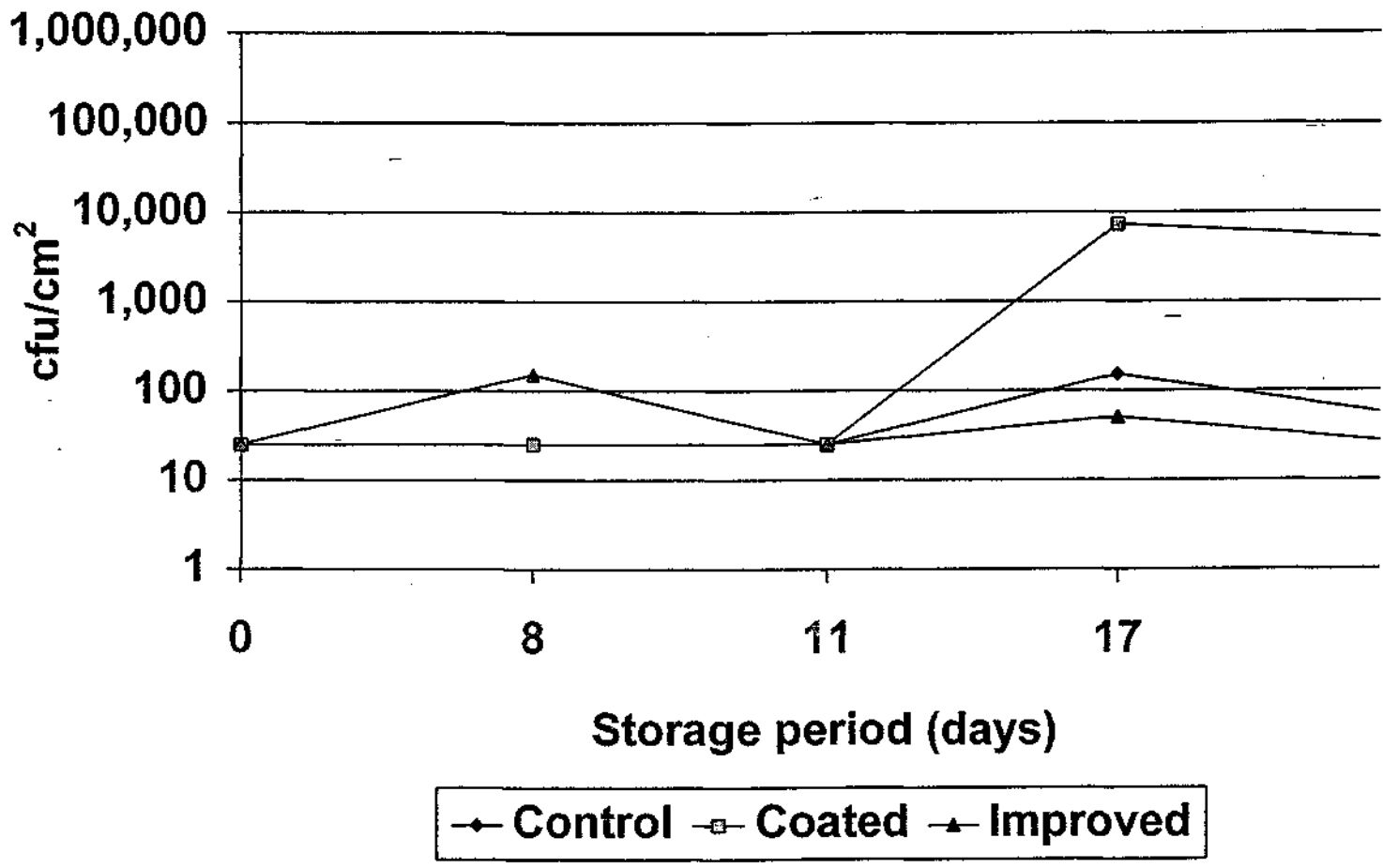

Fig. 4.13 Mould count on peeled potatoes during storage at 4°C

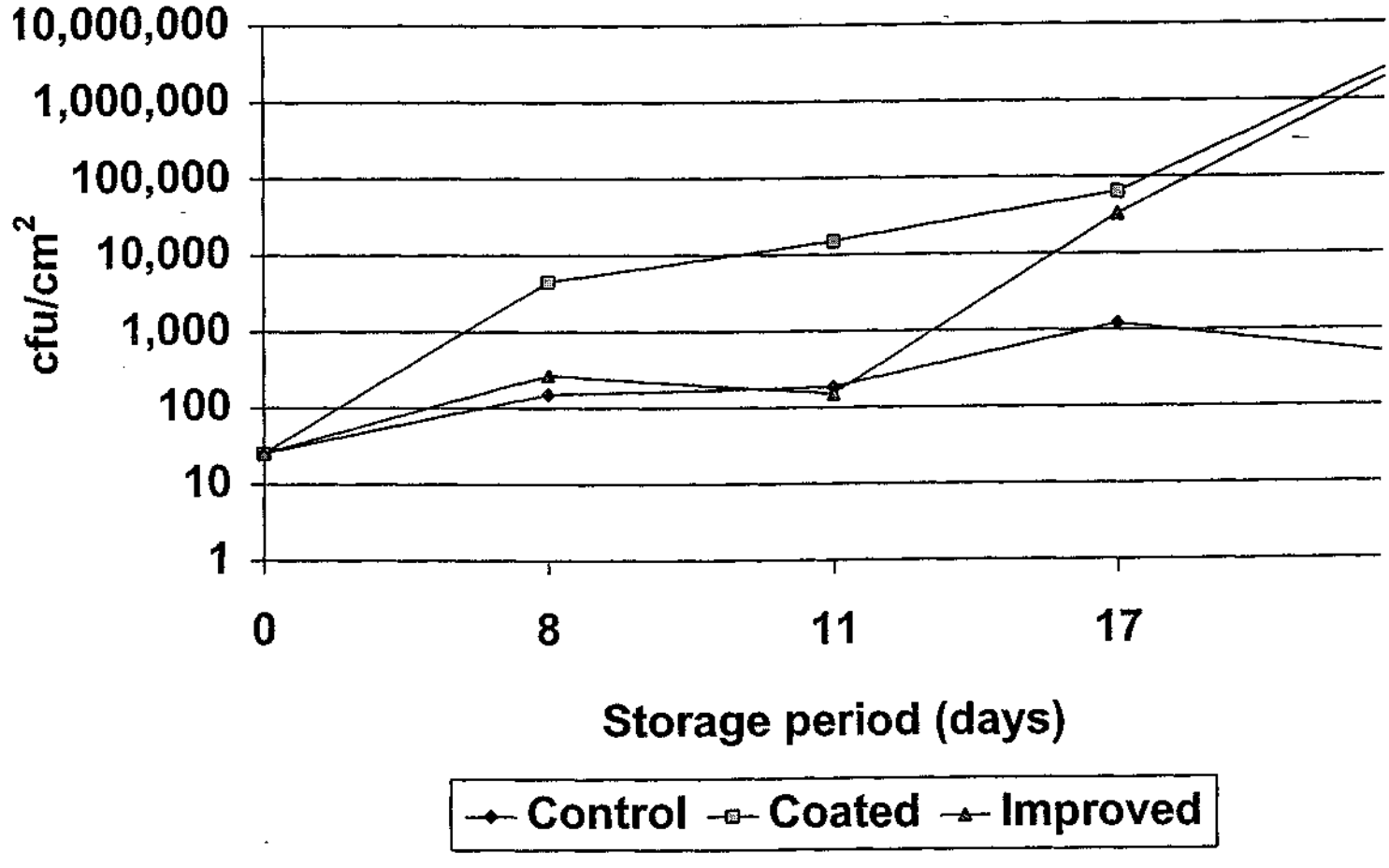

Fig. 4.14 Yeasts count on peeled potatoes during storage at 4°C

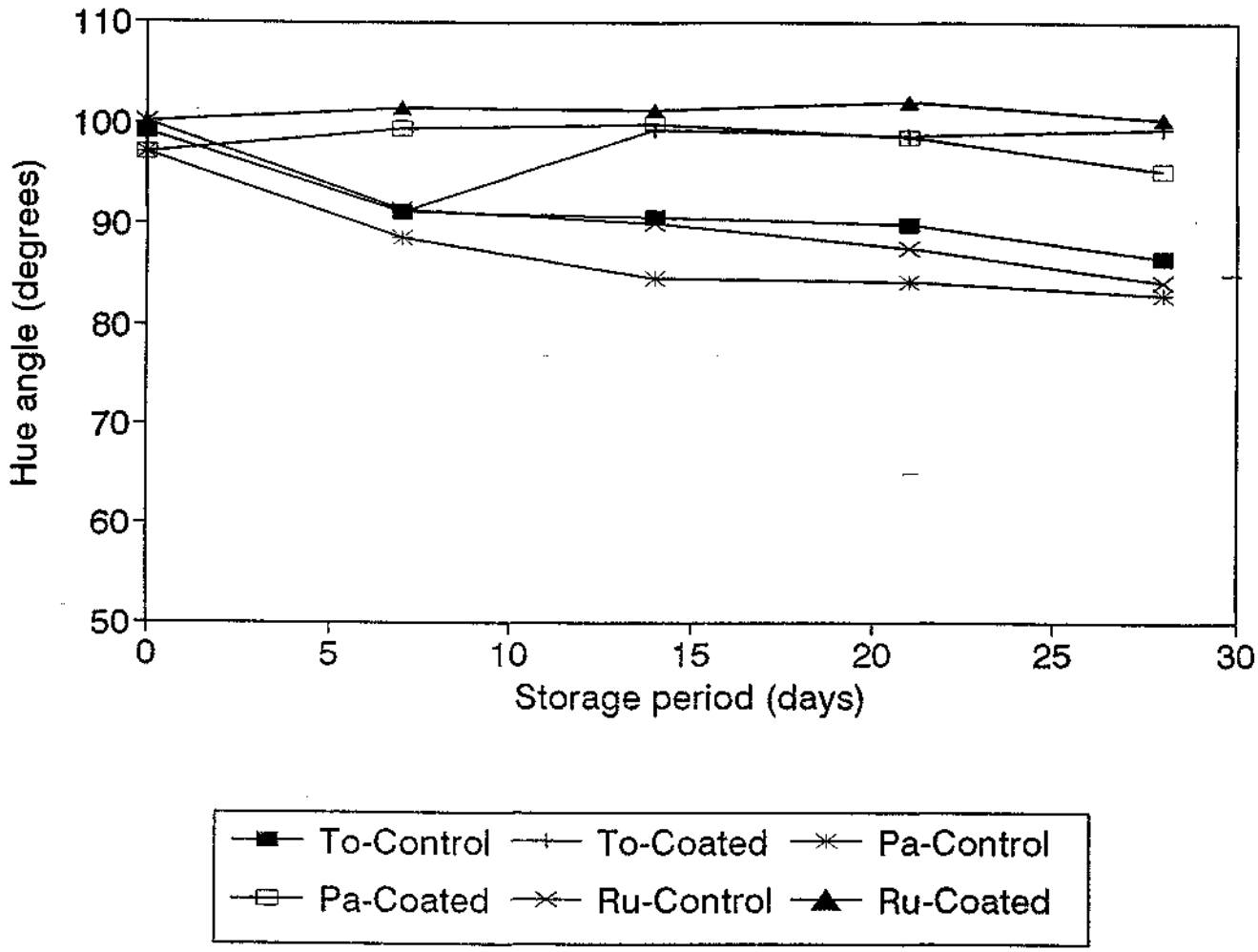

Fig. 4.15 Changes in hue angle values of *Toolangi Delight (To)*, *Patrones (Pa)*, and *Russet Burbank (Ru)* potatoes during storage at 4°C

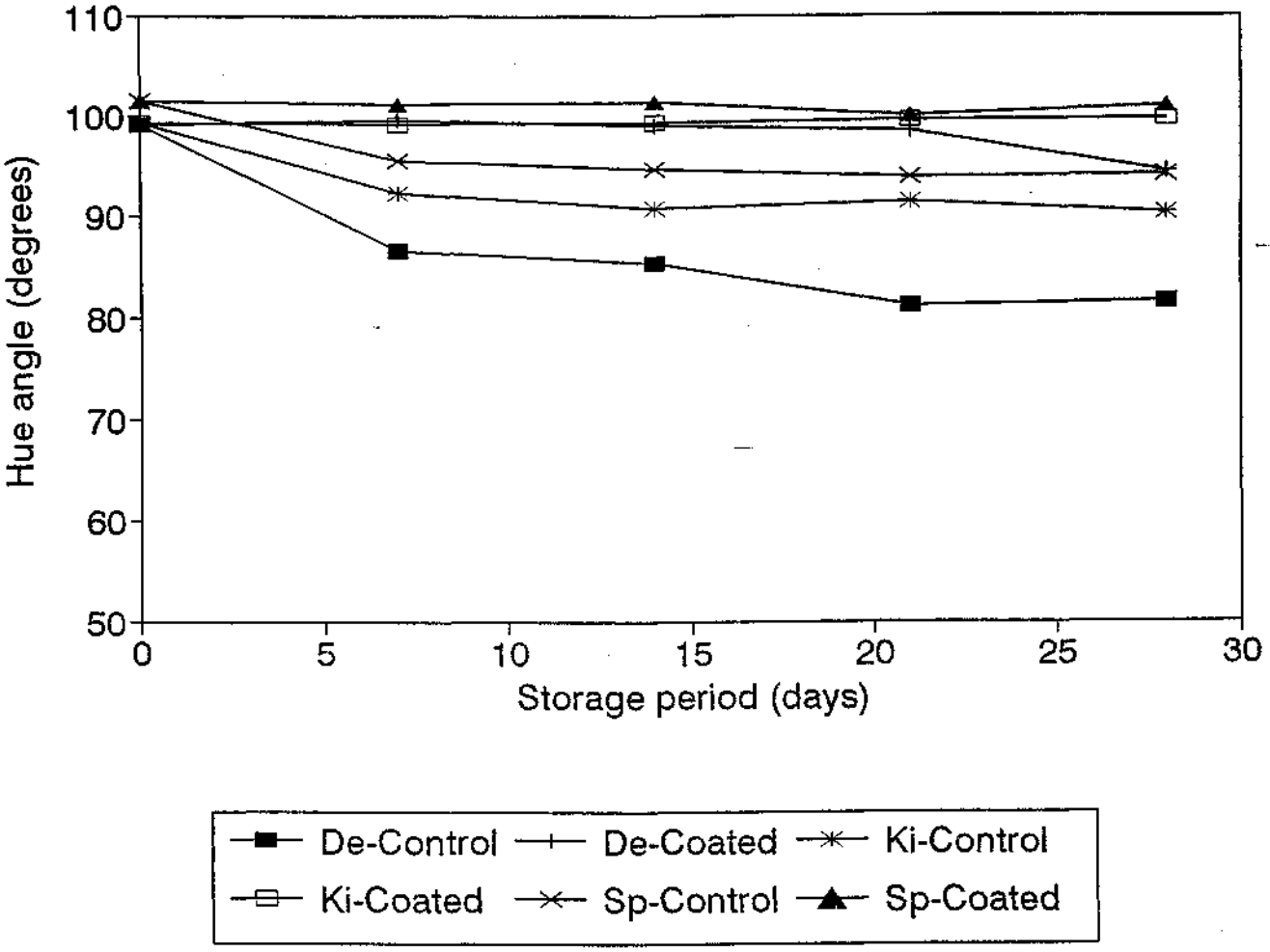

Fig. 4.16 Changes in hue angle values of *Denali (De), Kipfler (Ki)* and *Spunta (Sp)* potatoes during storage at 4°C

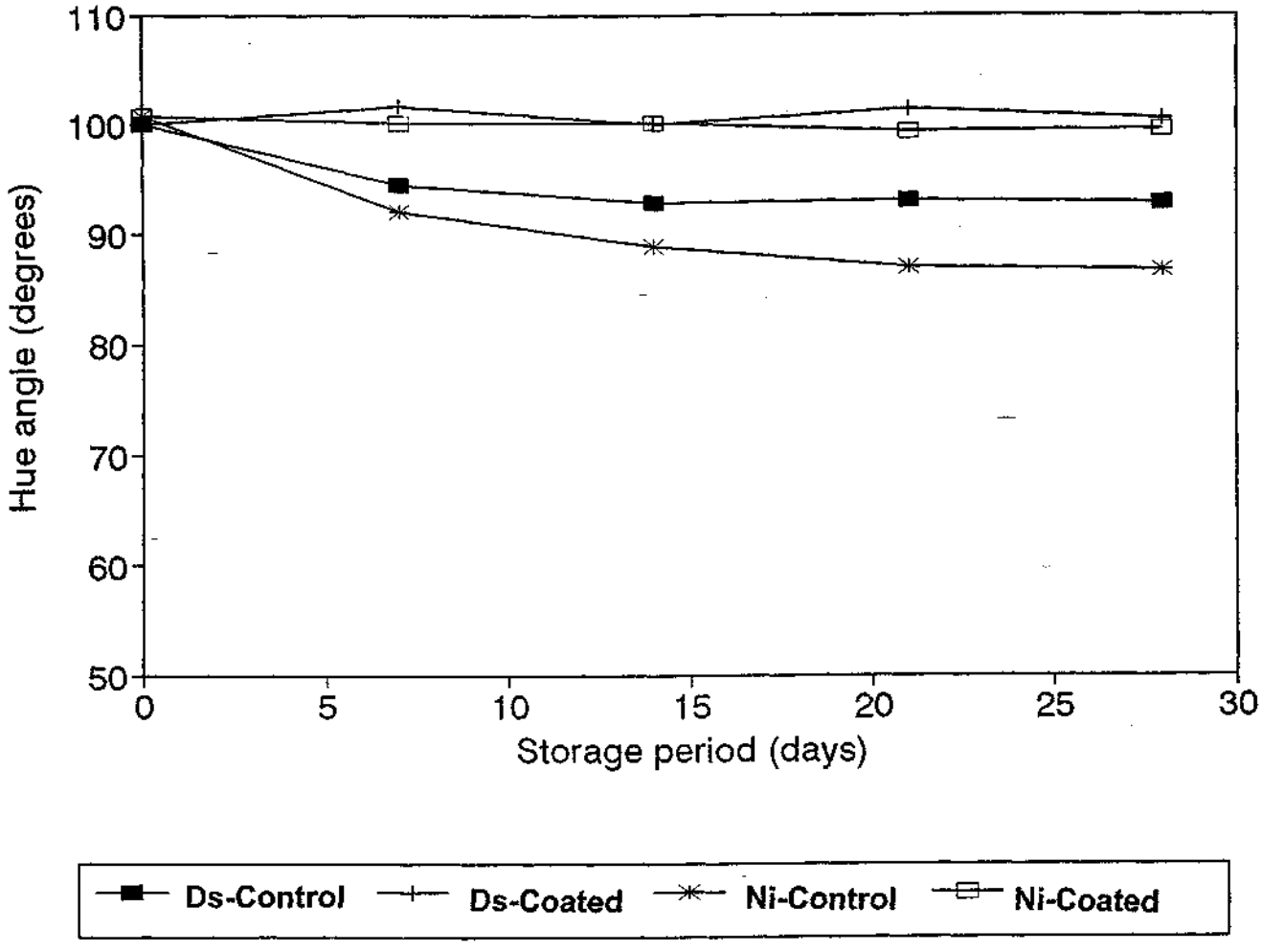

Fig. 4.17 Changes in hue angle values of *Desiree (Ds)*, and *Nicola (Ni)* potatoes during storage at 4°C

4.13 Preservation of French Fries by Vacuum and Modified Atmosphere Packaging

4.13.1 Selection of package

For treatments MA4 and MA10, the type and dimension of the packaging material, and the amount of French fries was designed to produce an equilibrium oxygen concentration of 2-3% at 4°C. The presence of 2-3% oxygen in the package headspace is important in order to allow the natural respiration of the fresh fries. In terms of the development of enzymatic browning, the presence of 2-3% oxygen will still be sufficient for enzymatic browning. Therefore, the shelf life of fresh fries packaged in 2-3% oxygen should be a conservative estimate compared to fries packaged under vacuum or gas flushed with very low oxygen level (*i.e.* <0.5%).

The development of 2-3% equilibrium oxygen level was accomplished by using a 50*u*m polyethylene blend to produce a bag size of 170mm x 230 mm containing about 300 to 400g of French fries. This corresponds to product weight to pouch surface area ratio in the range of 3.8 to 5.1 kg/m^2. This product to surface area ratio should be maintained when scaling-up the package for bulk packaging of French fries. Fig. 4.18 shows the equilibrium level of oxygen as a function of the amount of French fries from 200g to 400g in the pouch. Unless specified, each pouch used in this study contained 300g of French fries.

4.13.2 Changes in the colour of fresh fries

Based on hue angle values, all treatments of fresh and raw French fries exhibited an increase in brown colour as indicated by a decline in hue angle during storage at 4°C (Fig. 4.19). The reduction in hue angle was most dramatic in control or water-dipped samples during the 2nd and 3rd week of storage at 4°C. The average decline in hue angle was about 7 degrees per week which is considered to be extremely high. Assuming a 4 degree reduction in hue angle as a limit of acceptability, control samples have a shelf life of about a week. The other 4 treatments were considered acceptable in terms of hue angle for at least 3 weeks.

There are difficulties in adopting the hue angle value as the major criteria of colour acceptability in fresh French fries because a significant proportion of the browning discolouration occurs at the edges and tips of the fries. Because of this the lower limit of acceptability for hue angle was reduced from 7 degrees in whole potatoes to 4 degrees for French fries.

4.13.3 Changes in the of colour of cooked fresh fries.

In order to determine the effects of various treatments on the end-product, fresh French fries samples were fried at 180°C for 3 minutes. The colour of the cooked fries were measured in a similar manner as the fresh fries.

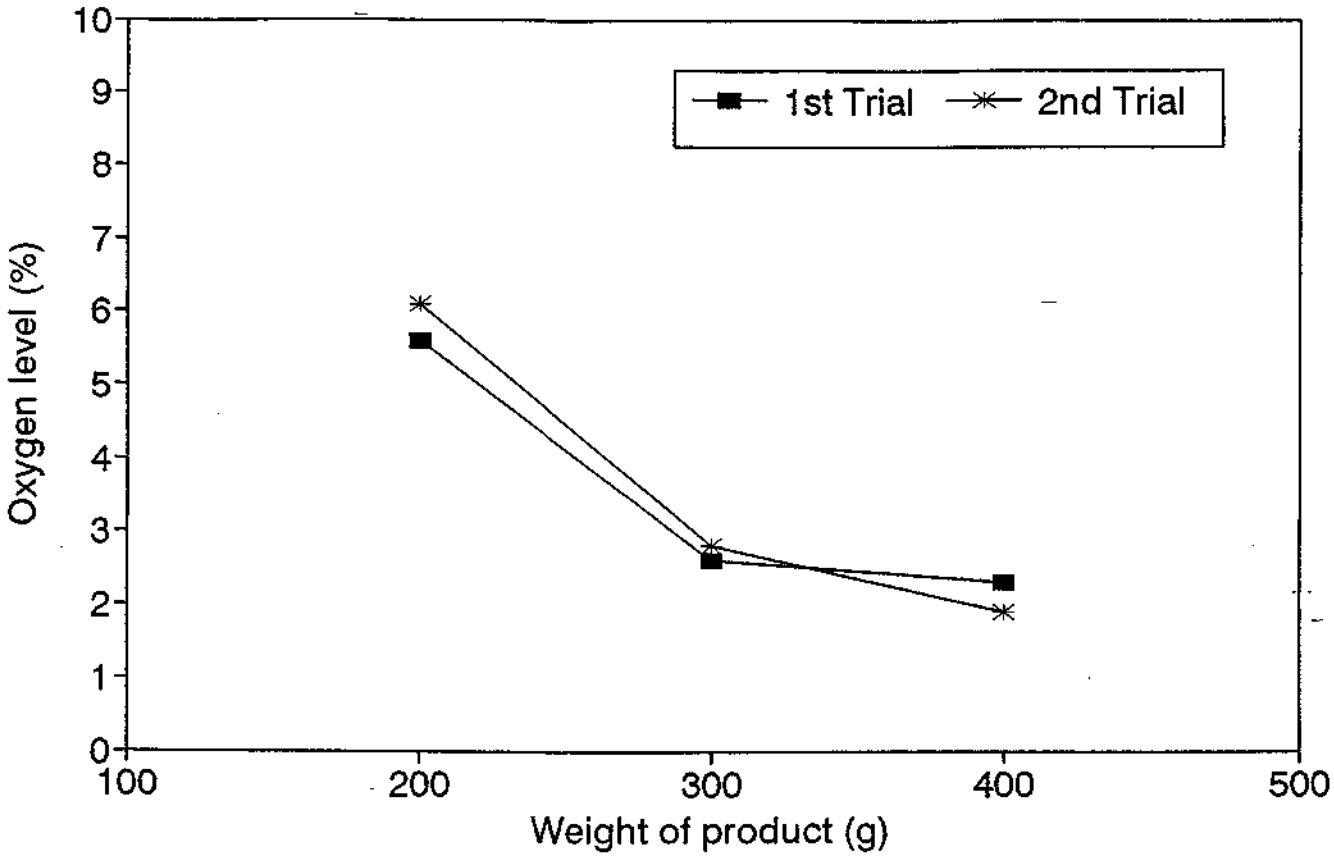

Fig. 4.18 Equilibrium oxygen level in the permeable package of fresh French fries stored at 4°C

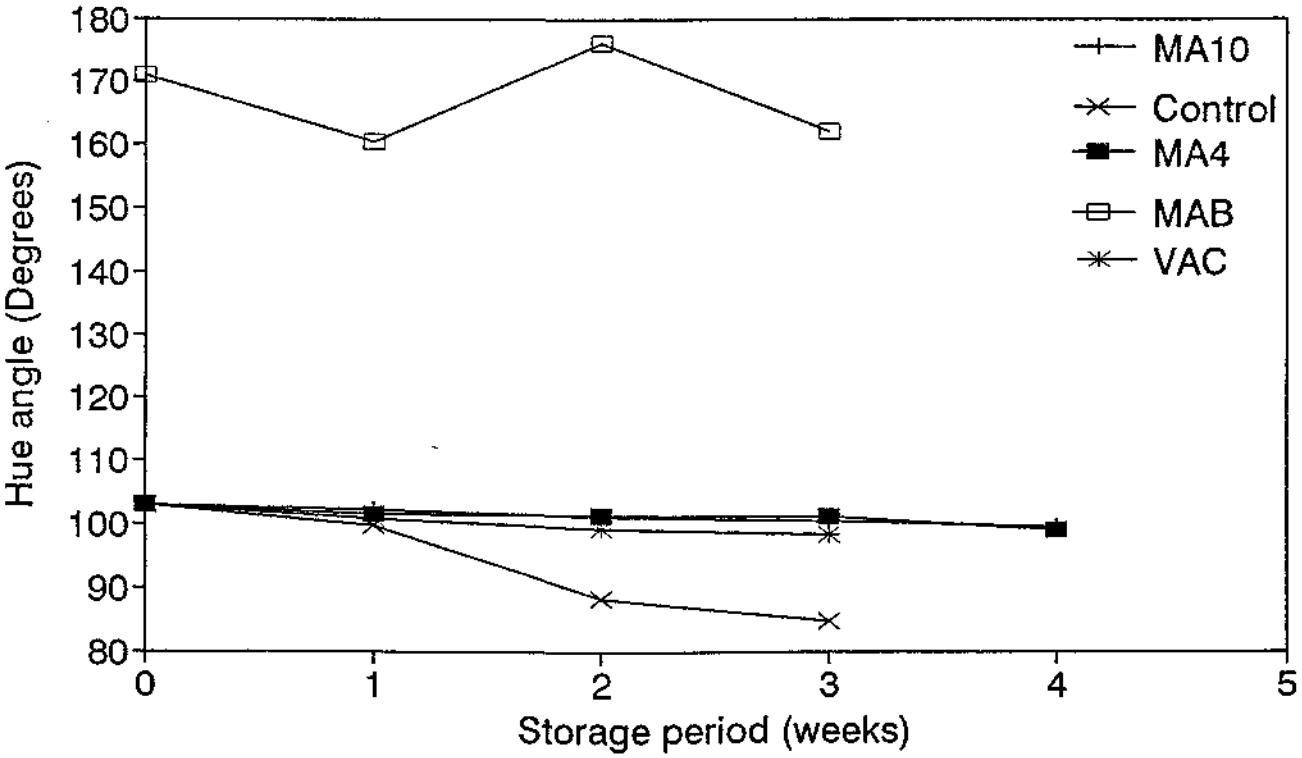

Fig. 4.19 Hue angle of fresh French fries during storage at 4°C

Fig. 4.20 shows the changes in the colour of the fried samples taken at various storage periods. Based on the hue angle readings, blanched samples (treatment MAB) exhibited the "lightness" colour as indicated by their high hue angle readings which was maintained during the 3 week storage period. Since the French fries industry in general prefers "lightly" coloured chips, treatment MAB is considered the best amongst the treatments considered in this study. It should be noted that treatment MAB exhibited an acidic taste due to the penetration of the antibrowning solution into the fries. In a commercial product, the acidic taste can be musked by the salt and other flavourings of the fries. The acidic taste would complement a French fries with a vinegar and salt flavour.

The package headspace of treatment MAB was designed not to include oxygen because the fries have been blanched which would inactivate most of the enzymes and prevent the product from respiring.

Treatments MA4, MA10, and VAC showed a slow but steady decline in hue angle values during storage. The order of increasing colour acceptability of cooked fries is as follows: control < MA4 ≤ MA10 ≤ VAC < MAB.

Based on the colour of fresh and fried samples, all treatments except for water-dipped samples were found to be acceptable from 2 to 3 weeks at 4°C in comparison with only 5 days in water-dipped samples. The end of shelf life was based on a 95° lower limit of acceptability for hue angle.

4.13.4 Microbiological results of French fries

No significant changes in yeasts and mould counts were detected in all treatments during the 2 week period of storage at 4°C. However, a slight increase in yeast count was detected in gas flushed treatments which were not blanched (MA4 and MA10). This could be due to the ability of some strains of yeasts to be acid resistant.

In terms of total aerobic count, vacuum packaged samples (VAC) exhibited the highest count with a peak of 1.3×10^5 on the 2nd week (Fig. 4.21). The total population declined on the 3rd week most probably due to increased competition with other microorganisms.

The risk of vacuum packaging without the aid of low pH is very obvious as shown by the *Enterbacteriaceae* count (Fig. 4.22). *Enterobacteriaceae* count in vacuum packaged samples (VAC) increase exponentially from 500 cfu/g to 2.3×10^5 within 3 weeks at 4°C.

In summary, the blanched gas flushed samples (MAB) gave the best result in terms of microbial population, and vacuum packed samples (VAC) the worst result. The poor microbial quality of vacuum packed samples (VAC) could be due to their high initial pH which was about 6.5. All gas flushed samples (MA4, MA10, MAB) had an initial pH of about 4 which gave them limited protection to some microorganisms (Fig 4.23).

Considering all the results of microbiological analysis, colour changes in both fresh and cooked samples, and the costs of antibrowning agents, the use of antibrowning solution based on 4% ascorbic acid and gas packaging with 40% carbon dioxide and 3% oxygen is recommended to produce fresh French fries with a shelf life of about 3 weeks at 4°C.

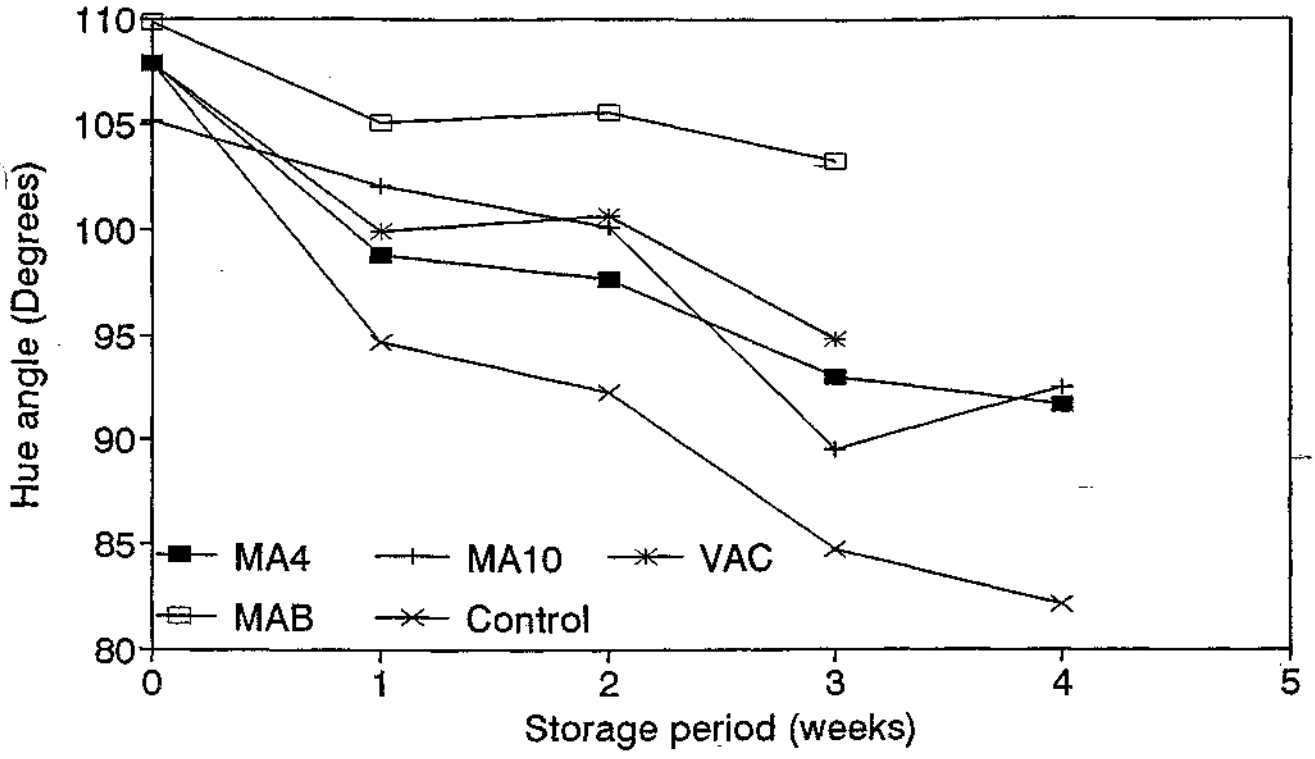

Fig. 4.20 Hue angle of French fries after frying

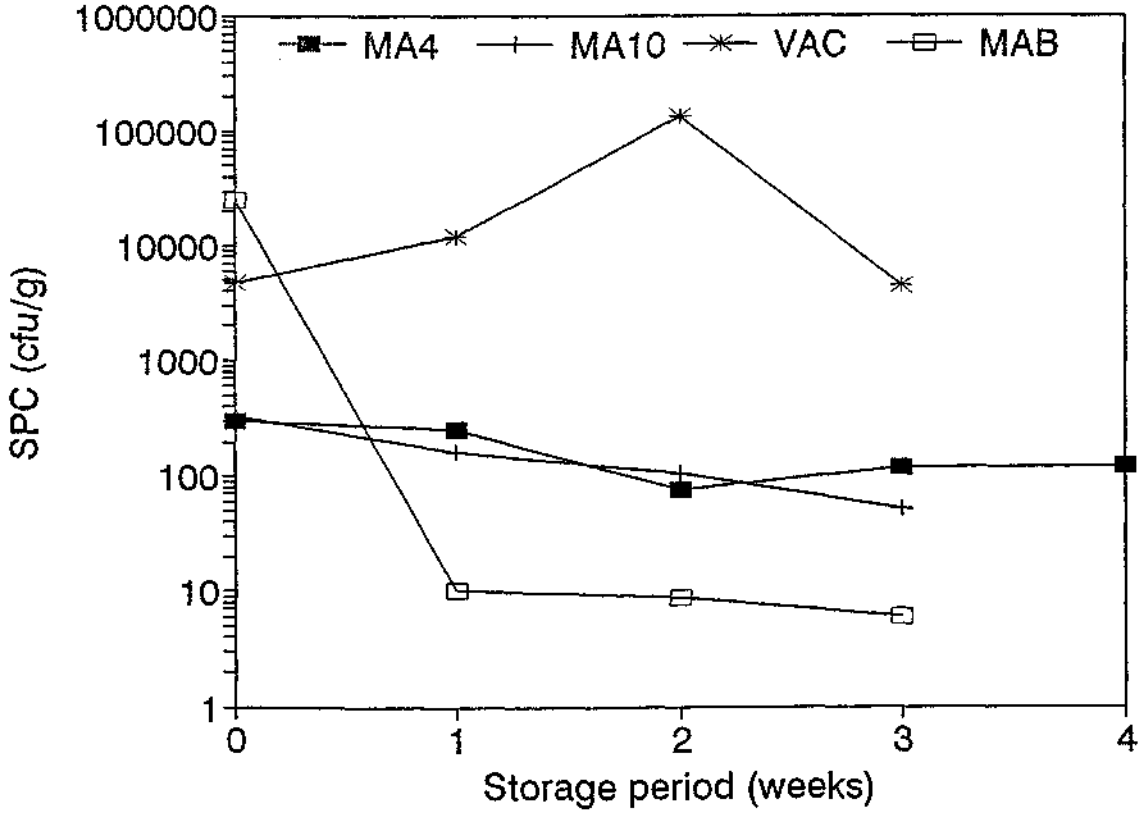

Fig. 4.21 Standard plate count of fresh French fries during storage at 4°C

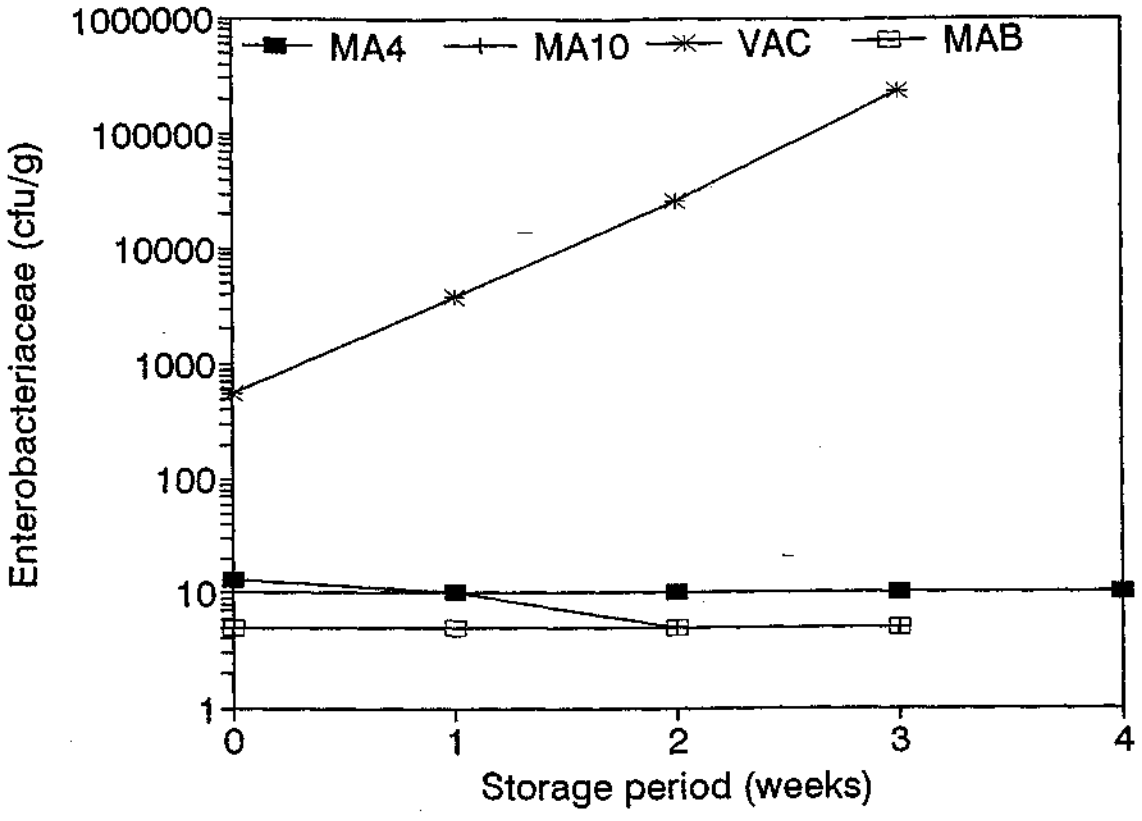

Fig. 4.22 ***Enterobacteriaceae*** **counts from fresh French fries stored at 4°C**

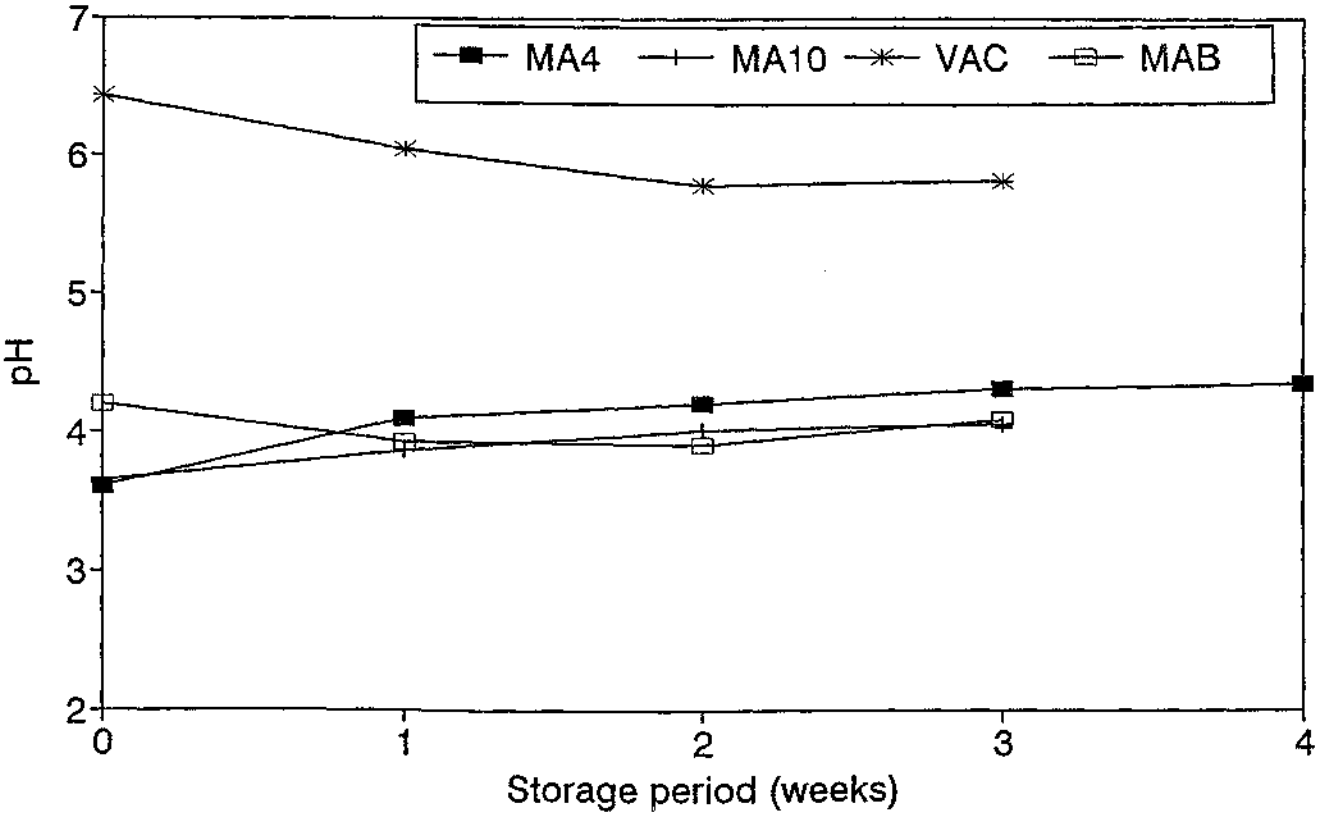

Fig. 4.23 Surface pH of fresh French fries during storage at 4°C

5.0 SUMMARY AND CONCLUSIONS

A market research conducted in 1993 on behalf of the Australian Potato Industry Council and supported by the Horticultural Research and Development Corporation revealed that a significant proportion of the population were not satisfied with the quality of potatoes presented for sale. The study also showed that consumption of fresh potatoes was much lower by people up to the age of 40 than by people in the 50+ age category. It was suggested that the marketing of fresh potatoes in pre-prepared formats (whole peeled, wedges, potato balls etc) could serve the impetus in increasing the consumption of potatoes.

Consumers desire for convenience and freshness has created a market for new products such as pre-prepared (washed, peeled and/or sliced) potatoes for boiling. However, these fresh product rely heavily on the use of sulphur dioxide and vacuum packaging which gives a very short shelf life. Hence, this project was developed and implemented in order to develop and evaluate the effectiveness of an integrated processing, packaging, and controlled storage and handling as an alternative to freezing and/or the use of sulphur dioxide in extending the shelf-life of fresh peeled potato products.

This project was able to develop and evaluate an integrated system for extending the shelf-life of pre-peeled potatoes without the use of sulphur dioxide under commercial processing conditions. The developed novel system was proven to maintain the quality and safety of pre-peeled potatoes up to 2 to 4 weeks under refrigerated conditions. The developed system integrates the following technologies: (i) encapsulation of the potato with an edible coating, (ii) incorporation of ascorbic and citric acid-based anti-browning agents in the coat, (iii) packaging in semi-permeable films, and (iv) low temperature storage. Shelf-life trials using commercially knife-peeled, steam-peeled, and abrasive-peeled potatoes showed inhibition of both enzymatic browning and microbial growth of up to 3 weeks at 4°C and up to 4 weeks at 1°C. Current shelf-life of peeled potatoes treated with sodium metabisulphite and vacuum packaged is about a week. Challenge experiments conducted by inoculating the potatoes with selected microorganisms have demonstrated the effectiveness of the developed system in guaranteeing the quality and safety of pre-peeled potatoes.

Enzymatic browning and microbial growth were found to be the main factors limiting shelf-life of pre-peeled potatoes. Sulphur treated and vacuum packaged potatoes were limited in shelf-life by anaerobic fermentation with associated production of off-odours and flavours. Potatoes processed and packaged using the developed preservation system were found to be limited in shelf-life by the growth of yeasts. Further extension in shelf-life can be achieved by the incorporation of approved level of organic preservatives in the coating.

The final processing, packaging and storage protocol has been verified to be applicable to potatoes peeled commercially by steam and abrasive systems. Steam peeled potatoes which have more severe tissue damage compared with mechanically peeled potatoes were preserved up to 15 days at 4°C by the developed preservation system. By comparison, untreated control samples exhibited a shelf-life of less than a day due to "after-cooking darkening". Addition of sodium acid pyrophosphate (SAPP) which is generally recommended for heat treated potatoes did not offer additional protection against "after cooking darkening".

The new preservation system in its present form was found to be ineffective in preserving lye-peeled potatoes. The presence of residual sodium hydroxide on the surface of the lye-peeled potatoes hindered the effectiveness of the developed preservation system.

Afisc has successfully applied for the variation of Australia and New Zealand Food Authority (ANZFA) Food Standards Code to permit the use of edible coating and associated anti-browning agents. Australian growers and processors can now produce and market pre-peeled potatoes without sulphur dioxide for the domestic market. It is expected that overseas markets especially Asia would permit the marketing of potatoes prepared by the developed system since most of the ingredients are currently classified as GRAS (Generally Regarded As Safe) substances.

6.0 RECOMMENDATIONS AND FURTHER WORK

Directions for extension and future or other activities

The use of the developed preservation system based on edible coatings is a relatively new approach in Australia and overseas markets. Approval by ANZFA to permit the use of some edible coatings has been applied and secured by Food Science Australia last May, 1997 (Appendix C). Potential processors, growers, and packers are now legally permitted to market pre-peeled potatoes processed using the newly developed system in Australia.

It is recommended that informal demonstrations of the developed technology be conducted by the Food Science Australia, and HRDC for existing and potential processors of potatoes, food service and institutional users, and retailers of pre-peeled potatoes. This informal demonstrations is recommended to be the major method of technology transfer for the developed technology.

Commercial benefits of adoption of research findings

The preservation systems developed from this study is not only an effective sulphur-free method of preserving and quality and safety of pre-peeled potatoes. The application to vary the ANZFA Food Standard Code was made on May 1995, however the new standard became official only last May 1997.

Restriction in the use of sulphur dioxide by various importing countries and the short shelf life of pre-peeled potatoes limit its export potential. The application of the developed preservation system that excludes the use of sulphur dioxide will definitely increase the export potential of pre-peeled fresh potatoes from Australia. Doubling of export of fresh potatoes is valued at about $5 million.

The availability of "ready-to-use" pre-peeled potatoes in the chill sector of supermarkets could encourage the consumption of potatoes which is currently either static or declining. Assuming that the "new variety" of chilled potatoes can increase consumption of about 10% of the current value of frozen potatoes ($40m), an estimated $4m could be realised.

Extension/adoption by industry of research findings:

Initially the developed technology was protected by a patent application. A non-agreement with potential licensees did not materialise hence the patent application was abandoned.

Marketing of the product was also hindered by the slow process to vary the ANZFA Food Standards Code in order to permit the use of the coating ingredients. The application to vary the ANZFA Food Standard Code was made on May 1995, however it took 2 years before the permission was grated last May 1997.

The "concept" of the newly developed preservation system has been introduced to a variety of potential uses including growers, processors, packers, and supermarket retailers. A market survey was conducted by Afisc on behalf of the potential licensees. The results of the market survey was very encouraging, however the report is confidential to the potential licensees.

The following is a list of selected publications that were used to present the "concept" of edible coatings for pre-peeled potatoes and other horticultural products:

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Preservation of exposed underground plant structures. PCT/AU95/00416 (Australian Patent PM6775/94) - Abandoned.

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Appendix A

Respiration Rate of Peeled Potatoes

Variety	Respiration rate (mL/kg.h)	Temperature (°C)
Sebago	0.461 (0.036)	-1.0
Sebago	1.203 (0.001)	1.5
Sebago	1.612 (0.095)	4.0
Desiree	1.650 (0.050)	4.0
Sebago	40.835 (8.918)	15.0

**Values in parenthesis are standard variation based on 3 replicates.*

Appendix B

Calculation of the Amount of Coating

The amount of coating on the potatoes was measured as the weight gained and thickness. The percentage weight gain was based on potatoes with an average weight of 102 grams. Table B.1 gives a summary of the results based on the 102g size potato. In less viscous solution which produced a "glazed" coating, weight gained ranged from 3.3% (w/w basis) in knife-peeled and 4.7% in abrasive-peeled tubers. This corresponds to about 0.1% alginate in knife-peeled and 0.14% in abrasive-peeled tubers. The thickness of the glaze coating ranged from 0.29 to 0.48mm.

In the most viscous solution 3% DM, the method of peeling did not seem to affect the uptake of the alginate coating. The weight gained in both abrasive and knife-peeled tubers was about 8.3% (0.25% alginate). The measured thickness of the coating was about 1 mm.

In medium range viscosity (2% DH, 1% DM), the method of peeling did not influence the amount of coating or weight gained which was calculated at about 7% (0.21% alginate).

Table B.1 Thickness and amount of coating on potatoes

Type of Coating & Peeling	Weight Gain (%)	Thickness (mm)	Amount of Alginate (%)
1. DM + Abrasive	8.29 (0.45)	0.89 (0.17)	0.249 (0.013)
2. DM + Knife	8.28 (0.36)	0.94 (0.25)	0.248 (0.011)
3. Mixed + Abrasive	7.20 (0.72)	0.83 (0.25)	0.216 (0.022)
4. Mixed + Knife	6.85 (0.21)	0.82 (0.27)	0.206 (0.006)
5. DH + Abrasive	4.66 (0.36)	0.48 (0.18)	0.140 (0.011)
6. DH + Knife	3.26 (0.10)	0.29 (0.10)	0.099 (0.003)

Numbers in parenthesis are standard deviation values based on 4 measurements

APPENDIX C

ANZFA AMENDED FOOD STANDARDS CODE - STANDARDS A10 - MODIFYING AGENTS AND F1 - VEGETABLES AND SIMILAR FOODS

- **Final Approval (May 1997)**
- **Publication in the Commonwealth Gazette- Government Notice**
- **Application Notice (November 1995)**

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Dear Dr Reyes

AMENDMENT TO THE FOOD STANDARDS CODE - STANDARDS A10 - MODIFYING AGENTS AND F1 - VEGETABLES AND SIMILAR FOODS

I wish to advise you that Amendment No. 34 to the Australian *Food Standards Code* containing Application No A252, Agar, Alginic Acid and Alginates for Coating Raw Peeled Potatoes, was published in the *Periodic Commonwealth Gazette* No P13 on 15 May 1997.

Copies of the Gazette are available from the Commonwealth Government Bookshop in your capital city.

Yours sincerely

Les Bienkiewicz
Standards Liaison Officer

29 May 1997

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Dear Dr Reyes

APPLICATION A252 - AGAR, ALGINIC ACID AND ALGINATES FOR COATING RAW PEELED POTATOES

The National Food Authority received an application (A252) on 18 May 1995 from the Australian Food Research Institute to provide permission to use agar, alginic acid and alginates (sodium, potassium, calcium and ammonium salts) as coatings for raw peeled potatoes.

The Authority has completed a full assessment of the application and has extended the scope of the application to include permission for all vegetable gums. The Authority has prepared a draft variation to Standard F1 - Vegetables and Similar Foods, and will now conduct an inquiry to consider the draft variation.

This matter will be published in the *Commonwealth Gazette-Government Notices* and *The Australian* newspaper on 15 November 1995.

A briefing paper is enclosed for your information.

Yours faithfully

Les Bienkiewicz
Standards Liaison Officer

14 November 1995

REGULATORY IMPACT STATEMENT

The Draft Regulatory Impact Statement concludes that the amendment to Standards L1—Vegetables and Similar Foods will permit potato processors to use vegetable gums to retard browning in fresh peeled potatoes. The proposed extension of vegetable gums should benefit consumers and commercial trade of fresh peeled potatoes from the convenience of a ready to cook product that stores well in refrigeration.

The Authority is required to formally assess the impact of any draft standard (or amendment) on all sectors of the community, including consumers, the food industry and governments. The assessment may include (but not be limited to) the identification and evaluation of the impacts be they financial, economic or social (including health).

To assist in this process, public submissions should clearly identify relevant impact(s) and provide supporting documentation where possible.

WORLD TRADE ORGANIZATION (WTO) NOTIFICATION

This matter may be notified to the WTO to enable other members of the WTO to make comment. Matters relating to public health and safety are notified to the WTO as a Sanitary or Phytosanitary notification, and other matters are notified to the WTO as a Technical Barriers to Trade (TBT) notification

INVITATION FOR PUBLIC SUBMISSIONS

The Authority has completed a full assessment of the application, prepared a draft variation to the Food Standards Code and will now conduct an inquiry to consider the draft variation and its regulatory impact.

Written submissions containing technical or other relevant information which will assist the Authority in undertaking the inquiry are invited from interested individuals and organisations. Where possible, technical information should be presented in sufficient detail to allow independent scientific assessment.

The processes of the Authority are open to public scrutiny, and any submissions received will ordinarily be placed on the public register of the Authority and made available for inspection. If you wish any confidential information contained in a submission to remain confidential to the Authority, you should clearly identify the sensitive information and provide justification for treating it in confidence. The *National Food Authority Act 1991* requires the Authority to treat in confidence trade secrets relating to food and any other information relating to food, the commercial value of which would be or could reasonably be expected to be, destroyed or diminished by disclosure.

Submissions should be received by the Authority by 3 January 1996.

All correspondence and submissions on this matter should quote the full title, Application No. A252 and be addressed to the Standards Liaison Officer at the above address.

November 1995

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EXPLANATORY NOTES

APPLICATION A252

AGAR, ALGINIC ACID AND ALGINATES FOR COATING RAW PEELED POTATOES

The National Food Authority has before it an application (A252) received on 18 May 1995 from the Australian Food Research Institute to amend the Australian Food Standards Code to extend the use of agar, alginic acid and alginates (sodium, potassium, calcium and ammonium salts) as coatings for raw peeled potatoes.

The action of peeling potatoes effectively changes their nature and durable life. Preserving techniques, such as a surface treatment, are considered appropriate to prevent premature spoilage of the peeled product as compared to the unpeeled counterpart. Because peeled potatoes are no longer in their natural state and require some treatment to retard browning, they should not be considered "unprocessed".

The applicant claims that coating raw peeled potatoes with these vegetable gums, together with permitted additives in clause (2A) (a) of Standard F1—Vegetables and Similar Foods can significantly increase the shelf life of the product when stored at refrigeration temperatures.

The permissions sought are proposed to be extended to include all vegetable gums listed in Group I of Standard A10—Modifying Agents. This is consistent with the safety assessment of vegetable gums and should facilitate further innovation in the potato processing industry.

Standard S1 permits miscellaneous foods to contain modifying agents which includes vegetable gums. Therefore, a mixture of raw peeled potatoes with another food, for example raw peeled carrots, would be permitted to have vegetable gums added.

PROPOSED DRAFT VARIATION TO THE FOOD STANDARDS CODE

Standard F1 is varied by inserting after paragraph (2A)(a)(v)-
"(vi) vegetable gums specified in Group I of Table 1 in Standard A10".