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Review Article

Section 5k

The inhibition of enzymatic browning in minimally processed vegetables and fruits

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ABSTRACT

Control of enzymatic browning in minimally processed vegetables and fruits has received a great deal of attention by researchers because of its importance to the food processing industry. Browning reactions in vegetables and fruits become evident when, for instance, food material is subjected to processing or to mechanical injury. Historically, enzymatic browning has been controlled by the application of sulphites; however, there is a need to substitute sulphites with other methods. The most frequently studied alternative to sulphite is probably ascorbic acid. Current thinking suggests prevention of browning is most effective using an integrated approach where all stages of processing are optimized. In this mini-review, chemical, enzymatic and physical methods for preventing browning of vegetables and fruits have been compiled without neglecting the significance of raw material, peeling and packaging.

Introduction

Consumers are increasingly asking for convenient, ready-to-use and ready-to-eat fruits and vegetables with fresh-like quality, containing only natural ingredients (Lund, 1989). In Finland, browning of potatoes has been a difficult problem for industries preparing potato salads and potato casseroles. Hitherto, sulphites have been used to prevent browning, but recently other alternatives have been studied.

Finnish regulations concerning sulphite compounds are congruent with EU Directives on sulphite compounds. The highest allowed amount of sulphite compounds, calculated as SO_2, depends on the foodstuff but there are only a few limits for fresh vegetables and fruits, such as peeled potatoes (50 mg/kg or mg/l) and prepared (including frozen) potatoes (100 mg/kg or mg/l) (95/2/EU). In the US, sulphite compounds are generally recognized as safe when used in accordance with good manufacturing practice, except that they are not allowed to be used on fruits and vegetables intended to be served raw to consumers or sold raw to consumers, or to be presented to consumers as fresh (FDA, 1996).

Sulphites are multifunctional agents: they prevent enzymatic and non-enzymatic browning, control growth of microorganisms, act as bleaching agents, antioxidants or reducing agents and carry out various other technical functions. However, the use of sulphites has some disadvantages. In addition to being corrosive to machinery and destructive to nutrients, sulphites may produce tissue softening and off-flavours. Sulphite treatments can also be used in conjunction with vacuum packaging. In these situations, anaerobic conditions can be created which are conducive to anaerobic fermentation and the growth of pathogenic organisms.

Adverse health effects associated with sulphite usage, and an increase in consumer preference for fresh, natural foods have also been other powerful motives behind the search for a practical and functional alternative to sulphite agents (Langdon, 1987; Anonymous, 1991; McEvily *et al.*, 1991).

Control of browning with sulphite substitutes has been under examination and ascorbic acid is one of the browning inhibitors much dealt with. The search for alternatives has yielded compounds that are effective substitutes for only one or 2 of the functionalities obtained with sulphites. It is unlikely that a multifunctional sulphite substitute can be developed. Rather, combinations of several active ingredients, formulated to meet the needs of specific commodities and product types, will be developed. Such formulations must be cost-effective in their stated use and they must be approved for food use (Sapers & Miller, 1993). The extent of usage of these inhibitors is not very well known.

The following commercial non-sulphite browning inhibitors have been examined: Snow Fresh™ and Potato Fresh™

(Maga, 1995), Sporix™ (Sapers *et al.*, 1989; Gardner *et al.*, 1991) and EverFresh™ (Lozano-de-González *et al.*, 1993). However, it seems that they are not as effective as sulphites. Therefore, research and development work for finding an effective substitute is still ongoing.

This mini-review aims to present the most recent knowledge on the inhibition of enzymatic browning in minimally processed vegetables and fruits.

Factors affecting enzymatic browning

Enzymatic browning requires 4 different components: oxygen, an enzyme, copper and a substrate. The most important enzyme in minimally processed vegetables and fruits is polyphenol oxidase (PPO). Polyphenol oxidase is a generic term for the group of enzymes that catalyse the oxidation of phenolic compounds to produce a brown colour on the cut surfaces of vegetables and fruits (Whitaker & Lee, 1995). Peeling and cutting are key steps in the preparation of minimally processed vegetables and fruits. During these operations cell membranes are broken, and appropriate substrates come into contact with oxidizing enzymes. In the presence of oxygen, rapid browning occurs due to the enzymatic oxidation of phenols to orthoquinones which rapidly polymerize to form brown or black pigments, such as melanins (Fig. 1).

Enzymatic browning or raw discoloration can proceed very quickly, even in 0.5 h. In the potato processing industry, minimally processed potatoes (whole, slices, strips) usually experience delays before further processing takes place. These delays may extend from an hour to several days (i.e. over a weekend) leading to the appearance of the above-mentioned defects. The most important factors that determine the rate of enzymatic browning of vegetables and fruits are the concentration of both active PPO and phenolic compounds present, the pH, the temperature and the oxygen availability of the tissue.

The optimum pH of PPO activity varies with enzyme source and with the substrate over a relatively wide range. In most cases, the optimum pH range of PPO is between pH 4 and 7. The adjustment of pH with acids to 4 or below can be used to control browning as long as the acidity can be tolerated tastewise. The temperature stability of PPO varies with species and with cultivars. The enzyme is relatively heat labile and activity is completely destroyed at 80°C (Vámos-Vigyázó, 1981). Heat inactivation of PPO is feasible by applying temperatures of more than 50°C but may produce undesirable colours and/or flavours as well as undesirable changes in texture.

The effect of raw material

Much can be done to reduce browning occurring during storage or processing by selecting cultivars of low browning tendency (Amiot *et al.*, 1992) and by appropriate agricultural techniques (Mondy & Munshi, 1993). The rate of brown discoloration in minimally processed vegetables varies according to pre- and postharvest factors. Among cultural factors, the choice of cultivar has been reported to have an effect on the browning potential of prepared potato, since different potato cultivars may have different chemical compositions. However, there are some indications that fertilizer practices may mask cultivar differences. Among the postharvest techniques that may affect browning, transport and storage of intact potatoes have been shown to play a role in the rate of browning of prepared potatoes.

The results of a Finnish study with various cultivars of 8 vegetables (Ahvenainen & Hurme, 1994) showed that not all cultivars of a specified vegetable can be used for processing for prepared vegetables. The correct choice of cultivar is particularly important for carrots, potatoes, swedes and onions. Weller *et al.* (1997) showed that cultivars or selections of carambola fruit could be selected with increased resistance to browning. Susceptibility to browning after slicing, packaging and storage for 4 weeks at 4.4°C varied considerably between 4 cultivars and 5 selections.

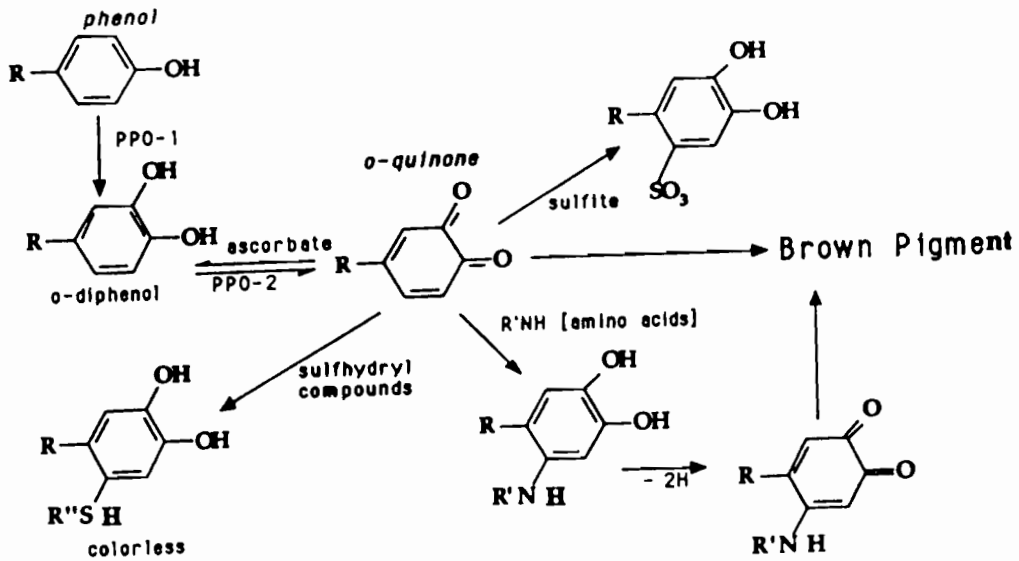

Figure 1. Reaction scheme for enzymatic browning (Labuza *et al.*, 1992)

The effect of processing

The correct and proper storage of vegetables and careful trimming before processing are vital for the production of prepared vegetables of good quality (Ahvenainen & Hurme, 1994; Kabir, 1994; Wiley, 1994). Some vegetables or fruits, such as potatoes, carrots or apples, need peeling. There are several peeling methods available, but on an industrial scale peeling is normally accomplished mechanically (e.g. rotating carborundum drums), chemically or in high-pressure steam peelers (Wiley, 1994). Peeling should be as gentle as possible (Ahvenainen & Hurme, 1994; O'Beirne, 1995). The ideal method would be hand-peeling with a sharp knife. Ahvenainen *et al.* (1997) found that browning of potatoes peeled with a carborundum peeler was more pronounced than that of potatoes peeled with knives. Carborundum-peeled potatoes must be treated with a browning inhibitor, whereas water was enough for hand-peeled potatoes. Potatoes peeled using a carborundum peeler also developed stronger off-odours. Sapers *et al.* (1989) showed that the method of peeling had a large effect on the extent of browning at the peeled surface. The decrease in *L*-value was greater for steam- or abrasion-peeled potatoes than for potatoes peeled with a sharp knife. According to Gunes and Lee (1997), hand peeling and lye peeling resulted in better quality, but abrasion peeling was undesirable for fresh potatoes.

Quality control of sliced potatoes is more difficult than that of whole pre-peeled potatoes. In ideal conditions whole pre-peeled potatoes can be stored without browning prevention chemicals for as long as 7 days (Ahvenainen *et al.*, 1997) but sliced potatoes cannot be stored without browning prevention chemicals (Laurila *et al.*, 1997).

The stability of shredded lettuce is affected by the way in which it is cut. Bolin *et al.* (1977) showed that shredded lettuce cut with a sharp knife using a slicing action had a storage life of about twice that of lettuce cut with a sharp knife using a chopping action. The shelf-life of cut lettuce was shorter when a dull knife was used.

Methods for preventing browning

In theory, PPO-catalysed browning of vegetables and fruits can be prevented by heat inactivation of the enzyme, exclusion or removal of one or both of the substrates (O_2 and phenols), lowering the pH to 2 or more units below the optimum, or adding compounds that inhibit PPO or prevent melanin formation (Whitaker & Lee, 1995). Many inhibitors of PPO are known, but only a few have been considered as potential alternatives to sulphites (Vámos-Vigyázó, 1981).

The most attractive way to inhibit browning would be 'natural' methods, such as the combination of certain salad ingredients with each other. Lozano-de-González *et al.* (1993) and Meza *et al.* (1995) have obtained promising results with pineapple juice. It appears to be a good potential alternative to sulphites for the prevention of browning in fresh apple rings. Treatment of white grapes and cut fruits with honey has been shown to inhibit PPO activity and browning. The inhibitory effect was due to a peptide of MW 600 (Oszmianski & Lee, 1990).

The browning susceptibility of potatoes could also be reduced to some extent by heat treatment (2 weeks at +15°C) before peeling. This is mainly due to the fact that the amount of reducing sugars decreases during the heat treatment (Mattila *et al.*, 1995). The results of recent research in browning prevention of potatoes, apples and iceberg lettuce are presented in Tables 1, 2 and 3, respectively.

Chemical methods

Probably the most frequently studied alternative to sulphite is ascorbic acid. This compound is a highly effective inhibitor of enzymatic browning, primarily because of its ability to reduce quinones back to phenolic compounds before they can undergo further reaction to form pigments. Unfortunately, once the ascorbic acid has been completely oxidized to DHAA (dehydroascorbic acid), quinones can accumulate and undergo browning. According to Sapers and Miller (1995) digestion with hot ascorbic acid/citric acid solutions improved the shelf-life of pre-peeled potatoes. A shelf-life of about 2 weeks was obtained. However, high concentrations of ascorbic acid (0.75%) imposed an unpleasant taste on the fruits (Luo & Barbosa-Cánovas, 1995). Ascorbic acid derivatives, like AAP and AATP, have been used as browning inhibitors alone or in combinations with other inhibitors for potatoes and apples (Sapers *et al.*, 1989; Sapers & Miller, 1992, 1993; Monsalve-González *et al.*, 1993). Erythorbic acid, an isomer of ascorbic acid, has been used as an inhibitor of enzymatic browning in combination with ascorbic acid or citric acid for potato slices (Dennis, 1993) and for whole abrasion-peeled potatoes (Santerre *et al.*, 1991). Lambrecht (1995) found that erythorbic acid and ascorbic acid were equally effective in preventing browning in pineapple slices.

Citric acid acts as a chelating agent and acidulant, both functionalities inhibiting PPO. Reliable and promising results have been obtained using citric acid and the combinations citric-ascorbic acid and benzoic-sorbic acid as dipping treatments for minimally processed potatoes (Mattila *et al.*, 1995). Weller *et al.* (1997) found that treating carambola slices with 1.0 or 2.5% citric acid and 0.25% ascorbic acid in water prior to packaging was very effective in limiting browning.

4-Hexylresorcinol (4HR) is one of the recently discovered, patented (McEvily *et al.*, 1991) and approved browning inhibitors of aromatic compounds. 4-Hexylresorcinol is a good inhibitor of enzymatic browning for shrimp, apples, potatoes and iceberg lettuce (Monsalve-González *et al.*, 1993; Luo & Barbosa-Cánovas, 1995; Whitaker & Lee, 1995; Castañer *et al.*, 1996). 4-Hexylresorcinol interacts with PPO and renders it incapable of catalysing the enzymatic reaction. 4-Hexylresorcinol has several advantages over using sulphites in foods, including its specific mode of inhibitory action, its effectiveness at lower levels, its inability to bleach preformed pigments, and its chemical stability (McEvily *et al.*, 1992). 4-Hexylresorcinol is the active ingredient in one commercial browning inhibitor, EverFresh™ (Lambrecht, 1995).

Ethylenediamine tetraacetic acid (EDTA), a complexing agent, has been used with potatoes (Cherry & Singh, 1990; Dennis, 1993) and iceberg lettuce (Castañer *et al.*, 1996) in combinations with other browning inhibitors. Sporix™, a chelating agent described by its supplier as an acidic polyphosphate, has been found to be an effective browning inhibitor in several fruits and vegetables (Sapers *et al.*, 1989; Gardner *et al.*, 1991)

Table 1. Browning inhibition methods studied for potatoes.

Treated material	Browning inhibitor (BI)	Other treatments and/or conditions	Results	Reference
1. Potato, ¼ -in thick slices	Potassium sorbate 0.2% w/w CA and AA 0.3, 0.5 or 1.0% w/w Sodium metabisulphite 500 or 1000 ppm	Treatment time 1 min, packaging in either 2 mil polylein multilayer bags (Cryovac B-900) or in 1.01 mil polyethylene bags, vacuum deaerating and sealing.	After 14 and 20 days, all potatoes treated with combinations of CA and AA and packaged in B-900 bags looked, smelled, and had the texture of freshly sliced potatoes and were as white as the sulphited potatoes in B-900 bags.	Langdon, 1987.
2. Potato, cut into pieces 2x1 cm in size and 2-4 mm thick	CA, AA, EDTA and cysteine in different concentrations alone, in combination or all together. The control samples were immersed in deionized water.	Treatment time 5 min, stored at room temperature or at 4°C for 6 days.	1. CA 78.4%, cysteine 3%, AA 15.6% and EDTA 3%. These 4 chemicals are mixed, dissolved in deionized water in an amount from 0.5 to 0.6% of the total formulation: The *L* value of 73 is reduced to 64 after 6 days. 2. CA 70.5%, cysteine 2.4%, AA 11.8%, EDTA 3.5% and sodium acid pyrophosphate or tetrasodium acid pyrophosphate 11.8% mixed and dissolved to produce a 0.6 to 0.7% solution: the same *L* levels as obtained with Example 1.	Cherry & Singh, 1990. Patent no: 4,937,085
3. Potato, whole, peeled	SPORIX compound 1.08, CA 1.08 and water 100 (part by weight)	Initial dip: 30 s Final dip: 120 s Packaged in polyethylene bags and stored at 32°-40°F (0°-4.4°C).	Shelf-life based on normal colour of the product in the packaging was 12 days. When the bag was opened, an acceptable fragrance was noted. After the bag was opened, potatoes were observed to hold their normal colour, in open air, for 7 h (longer cooking time, acceptable taste and texture after cooking).	Gardner *et al.*, 1991. Patent no: 4,988,523
4. White Russet Burbank, 4-5 mm thick slices	1. Sodium bisulphite 2. Sodium sulphhydrate 3. Sodium hydrosulphite 4. L-Cysteine 5. *N*-Acetyl-L cysteine 6. Glutathione (reduced) 7. Sodium salicylate 8. Mixed acids (a) 1% CA, 1% AA and 0.2% potassium sorbate; (b) 0.5% CA, 0.3% AA and 0.2% potassium sorbate.	Concentrations: 5, 10, 25 and 50 mM (adjusted to pH 7.0-7.5). Immersed for 1-2 min, placed on culture dishes or in plastic bags which were evacuated.	NAC and GSH (reduced), applied at 25 or 50 mM concentration, appear as effective as sodium sulphite in preventing browning of potatoes. The mixed-bath acids as sulphite alternatives appear to be of limited value.	Molnar-Perl & Friedman, 1990.
5. Russet Burbank whole, abrasion-peeled	Potatoes were dipped 1. In water for 2 min 2. In water for 2 min 3. In liquid containing 3% erythorbic acid + 2% NaCl + 0.25% SAPP for 2 min 4. In 2000 ppm bisulphite solution for 1.5 min	Solutions added to packages: 1. Water 2. 0.2% SA (potassium salt) + 0.2% CA 3. 0.2% SA (potassium salt) + 0.2% CA 4. -After BI treatment slices were drained, packaged in a solution as described, sealed in plastic bags and stored at 3.8°C.	Potatoes packaged in erythorbic acid and/or CA solutions maintained lightness which was similar to or better than sulphited potatoes.	Santerre *et al.*, 1991.

Table 1. Browning inhibition methods studied for potatoes cont'd.

Treated material	Browning inhibitor (BI)	Other treatments and/or conditions	Results	Reference
6. Idaho White potato slices	1. No treatment 2. Citrate buffer, pH 5.2 3. $NaHSO_3$ 4. Papain 5. Ficin 6. Bacterial protease 7. Bromelain 8. Fungal protease	A series of 2% (w/v) enzyme solutions were prepared by mixing 2.5 g of each enzyme with 125 ml 0.1 M citrate buffer (pH 5.2). Treatment time 5 min, put in Petri dishes and stored at 24°C or 4°C in a desiccator saturated with water vapour so as to avoid surface dehydration of the samples.	Ficin was as effective as sulphite at 4°C but slightly less effective than sulphite at 24°C. Bacterial protease was effective at 24°C and papain was somewhat effective at 4 °C. Bromelain and fungal protease were generally ineffective in inhibiting browning at both temperatures.	Labuza *et al.*, 1992 and Taoukis *et al.*, 1989. International Patent no: WO 89/11227
7. Russet Burbank plugs, about 2.2 cm in diameter, 0.95 cm dice and pre-peeled tubers prepared by abrasion peeling or high pressure steam peeling	1. Conventional: 4% AA, 1% CA, 1% SAPP and 0.2% $CaCl_2$ 2. Experimental: 2.5% AA, 1% CA, 1% SAPP, 0.2% $CaCl_2$, 1.9% AAP (Na salt), 1.5% AATP (Na salt), and adjusted to pH 2 with HCl or H_3PO_4 3. Control sample was dipped in water for 20 s	Peeled tubers were briefly stored in a holding solution containing 2% SAPP and 0.25% NaCl prior to further treatment. Treatment time 1.5 or 5 min (plugs) and 5 min (dices), placing the treated samples in covered crystallizing dishes (plugs) and in plastic bags (dices), stored at 4°C.	The experimental treatment was more effective than the conventional dip. The storage life of samples was extended by about 1 week to 9 days for plugs and 13 days for dice. The use of H_3PO_4 for pH adjustment proved more effective than adjustment with HCl.	Sapers & Miller, 1992.
8. Potato, (Idaho Russet) abrasion peeled (60 s), cut into 3/8-inch French fries	Different concentrations of GDL (0-2%) and $NaHSO_3$ (0-0.5%) in dip solutions	Water used as holding solution. Treatment time 2-6 min, packaged into 2.7 mil polyethylene bags and stored under fluorescent lights at 40°F (4.4°C)	0.05% $NaHSO_3$ + 1.5% GDL was nearly as effective as 0.5% $NaHSO_3$ after 13 days' storage.	Weiss & Todd, 1992 Patent no: 5,162,127
9. Russet Burbank slices, 1 cm in thickness	1. 100 ppm $K_2S_2O_5$ 2. 2% L-AA + 1% CA + 0.1% $CaCl_2$ 3. 2% iso-AA + 1% CA + 0.1% $CaCl_2$ 4. 100 ppm EDTA 5. as 2 + EDTA 6. as 3 + EDTA 7. 1% L-AA + 1% iso-AA + EDTA + 1% CA + 0.1% $CaCl_2$	Treatment time 10 min, packaged in polyolefin bags (Clysar LLP shrink film), ½ of the bags were sealed without vacuum using a heat impulse sealer and the other ½ under vacuum using a vacuum heat impulse sealer. After sealing the bags were stored at 10°C.	The data suggest that any of the other treatments used would be a satisfactory substitute for $K_2S_2O_5$ as an antibrowning agent. The presence or absence of vacuum as part of the packaging method appears to have very little, if any, influence on raw potato quality.	Dennis, 1993.
10. Russet and round-white potatoes, a) abrasion peeled b) high pressure steam peeled (1400 kPa, 15.5 s) c) lye peeled (3 min in 17% NaOH at 88°C)	1. Conventional: 4% AA, 1% CA, 1% SAPP and 0.2% $CaCl_2$ 2. Experimental: 2.5% AA, 1% CA, 1% SAPP, 0.2% $CACl_2$, 1.6% AAP (Mg salt), and 1.5% AATP (Na salt) adjusted to pH 2 with H_3PO_4	Holding solution as in Sapers and Miller, 1992. Peeled tubers were digested by immersion in: 14-20% NaOH for 1-13 min at 20-55°C. Treated tubers were drained, placed in cold water, brushed to remove digested tissue, washed, and briefly stored in holding solution until treated with BIs. Immersed for 5 min in a BI solution. BI treated tubers were drained, packaged in plastic bags, and stored at 4°C.	Digestion extended shelf-life of high pressure steam- and abrasion-peeled potatoes to 13-15 days at 4°C, compared with 3-11 days for undigested controls. Lye digestion in conjunction with conventional browning inhibitors represents a viable alternative to sulphiting pre-peeled potatoes. Tuber storage temperature had no effect on response to digestion.	Sapers & Miller, 1993.

Table 1. Browning inhibition methods studied for potatoes cont'd.

Treated material	Browning inhibitor (BI)	Other treatments and/or conditions	Results	Reference
11. Potato, (Pentland Dell, Rooster, Record and Maris Piper) abrasion peeled, cut in half	Dipped in 1. 0.05% $Na_2S_2O_5$ solution 2. Water	Treatment time 30 s, drained, vacuum-packed in bags and stored at 4°C. Samples were evaluated for colour, texture, aroma and microbial status at 0, 7, 14 and 21 days.	The colour values did not change much by day 21 for samples with SO_2 but there was a large loss in whiteness and also a loss in yellowness for samples without SO_2. The presence or absence of SO_2 had a variable effect on the aroma score. The microbial data suggest a shelf-life of around 14 days.	Chassery & Gormley, 1994.
12. Russet and round-white potatoes, a) abrasion peeled b) high pressure steam peeled (1400 kPa, 15.5 s) c) lye peeled (3 min in 17% NaOH at 88°C)	Solution containing: 4% AA, 1% CA, 1% SAPP and 0.1-0.2% $CaCl_2$.	Holding solution as in Sapers and Miller, 1992 and 1993. Samples comprising 2- to 3-peeled tubers were immersed for 5-20 min in 2 litres of solution containing 0-2% AA, 0-2% CA, and, in some experiments, 0.1% $CaCl_2$, 0.5-1% SAPP or 200-1000 ppm EDTA, heated to 45-65°C, cooled in running tap water for 2 min. Treated potatoes and controls were dipped in a BI solution containing 4% AA, 1% CA, 1% SAPP, and in some experiments 0.1-0.2% $CaCl_2$ for 5 min. Packaged in 3.8-litre plastic bags and stored at 4°C for up to 2 weeks.	Combined treatment inhibited potato discoloration for 14 days at 4°C, compared with 3-6 days with BI treatment alone.	Sapers & Miller, 1995.
13. Potato, (Centennial Russet) 1. Whole, manually peeled, 2. French fry-cuts 3. American potato chips	1. Water 2. Snow Fresh™ (30 g/l) 3. Potato Fresh™ (7 g/l)	Samples were placed in heat-sealable polyethylene packaging and treated in one of the following 4 manners: 1. Just heat sealed (=control) 2. The air removed via the vacuum attachment and sealed 3. The vacuum removal of residual air and flushing with 20% CO_2 + 80% N_2 or 4. 80% CO_2 + 20% N_2 Solutions were prepared in 22°C tap water. All samples were permitted to soak for 10 min, and to drain for 3 min before being packaged and placed in the dark at 4°C. A group of 12 individuals was used to evaluate colour changes on a 10-point scale (10=white, 1=black).	Whole, peeled potatoes and fry cuts: the samples retained better colour with the Snow Fresh as compared with the Potato Fresh dip, while both dips were much more effective than the plain water treatment. Also, the vacuum treatment was more effective than leaving air in contact with the product. The modified atmosphere composed of 20% CO_2 + 80% N_2 was more effective than the other. Peeled raw slices: Potato Fresh was somewhat more effective than Snow Fresh. Slices were the most reactive form of potatoes evaluated. Combining dips in conjunction with modified atmosphere resulted in products that were still very acceptable even after 58 days of refrigerated storage.	Maga, 1995.
14. Bintje, Van Gogh and Nicola; slices	Water Citric acid 0.1%, 0.3% or 0.5% Ascorbic acid 0.1%, 0.3% or 0.5% Calcium chloride 0.1% Potassium sorbate 0.2% Sodium benzoate 0.1%, 0.3% or 0.5% 4-Hexylresorcinol 0.005% Sodium hydrogen sulphate 0.1% or 0.3% and their combinations	The temperature of potatoes and of the chemical bath was +5°C. The amount of liquid was 2 l/kg potato slices, the treatment time was one or 3 minutes. Potatoes were stored at +5°C and at 75% RH for one, 5 and 8 months before peeling. Heat treatment: 2 weeks at +15°C for potatoes stored for 8 months. Browning was measured by the so-called browning index, which is based on sensory evaluation using one trained panellist.	The combination of different chemicals prevented browning better than a specific chemical alone. Although the browning susceptibility of the 3 cultivars studied increased during long-term storage, it had only a very small effect on the effectiveness of the chemicals. By increasing the washing time from one to 3 minutes, the effectiveness of chemicals could be improved only slightly. The browning susceptibility could also be reduced to some extent by heat treatment before pre-peeling.	Mattila *et al.*, 1995.

Table 1. Browning inhibition methods studied for potatoes cont'd.

Treated material	Browning inhibitor (BI)	Other treatments and/or conditions	Results	Reference
15. Russet-Burbank potatoes, cuts	Control Water L-cysteine 0.5% L-cysteine 0.5% + citric acid 2% Ascorbic acid 5% Potassium metabisulphite 0.1%	1. Five solutions were tested on packaged potatoes. The cut potatoes were dipped into solutions for 3 min and a 400 g sample was placed into PD-941 packages which were flushed with a gas mixture containing 9% CO_2, 3% O_2 and the balance N_2 for 3 min and then stored at 2°C. 2. Cut potatoes dipped into a 0.5% L-cysteine and 2% citric acid mixture for 3 min, packaged using PD-941 material, and flushed with air, gas mixture, 9% CO_2 in N_2, or 100% N_2. 3. Potatoes were peeled by the abrasive peeler, a hand-peeler and a lye solution.	The L-cysteine (0.5%) and citric acid (2%) mixture prevented browning of potatoes effectively. Active modification of the atmosphere inside the package was necessary to achieve an extended shelf-life. Nitrogen flushing was more effective than other gas treatments with a highly permeable multilayered polyolefin material. Hand peeling and lye peeling resulted in better quality, but abrasion peeling was undesirable for fresh potatoes.	Gunes & Lee, 1997.
16. Two different lots of Van Gogh potatoes; pre-peeled, whole	Water Citric acid 0.1%, 0.3% or 0.5% Ascorbic acid 0.1% or 0.3% Calcium chloride 0.1% Sodium benzoate 0.1%	Sharp peeling knives or carborundum peeler were used. Treatment time was 3 min and the temperature was +5°C. 1 kg of potatoes was packed in 80-µm nylon-polyethylene packages, with gas mixture 20% CO_2 + 80% N_2 or vacuum. Potatoes were stored for one, 5 and 7 months at +5°C and at 75% RH before treatment. Microbiological and sensory analysis were done and vitamin C content was determined.	Cultivation and harvesting conditions and peeling method were the most important factors reducing the sensory quality, especially the appearance, of pre-peeled and sliced potatoes. The levels of vitamin C in packaged samples decreased during winter storage. Cooking and baking of potatoes decreased the appearance defects detected in raw potatoes and the content of vitamin C. Peeling, washing and packaging methods, cultivation conditions and winter storage did not have an important effect on the number of microbes present.	Ahvenainen *et al.*, 1998.
17. Van Gogh, Bintje and Fambo; sliced potatoes (5 mm)	Not treated Water washed Citric acid 0.1% or 0.5% Ascorbic acid 0.1% or 0.5%	Sharp peeling knives were used. Treatment time was 1 min and the temperature was +5°C. 1 kg of potatoes was packed in 80-µm PA-PE packages. Packaging atmosphere was either 5% O_2 + 20% CO_2 + 75% N_2 or 20% CO_2 + 80% N_2. The percentages of CO_2 and O_2 in the package head space, microbiological determinations, sensory evaluations and vitamin C analysis were carried out after packed samples had been stored for 1, 4 or 7 days.	The best sensory quality of potato slices was attained with washing solution containing 0.1-0.5% citric and ascorbic acid and with a gas mixture containing 20% CO_2 + 80% N_2. Fambo is not a suitable potato cultivar if slices are to be stored for several days. Oxygen concentrations in the package head space were less than 1.5% during the whole storage period. The number of microbes in sliced potatoes was low and did not affect the quality of sliced potatoes.	Laurila *et al.*, 1998.

Table 2. Browning inhibition methods studied for apples.

Treated material	Browning inhibitors (BI)	Other treatments and/or conditions	Results	Reference
1. Apple, (Red Delicious, Winesap) cut surface of plugs (22 mm diameter). Plugs were cut transversely at their midpoints.	Different concentrations of AAP, AA, AATP, CINN, SPORIX, NaA alone or in combination were used. Dips containing water-soluble AA derivatives were prepared with distilled water or 1% CA solution.	Treatment time 90 s, control sample 10 s in water, stored at room temperature for 2, 6 and 24 h. (Browning inhibitors were also tested in the juice system.)	AAP and AATP showed considerable promise as inhibitors of enzymatic browning at the cut surface of raw apple, but were ineffective in apple juice. Dips containing combinations of Sporix and AA were highly effective in inhibiting enzymatic browning on the cut surface of apple plugs.	Sapers *et al.*, 1989.
2. Apple, (Red Delicious) 5-mm thick pieces of about 4 cm diameter	1. No treatment 2. Citric acid, pH 4.5 3. Sulphite 4. Papain 5. Ficin 6. Bacterial protease 7. Bromelain 8. Fungal protease	A series of 2% (w/v) enzyme solutions was prepared by mixing each enzyme with 125 ml 0.1 M citric buffer (pH 4.5). Treatment time 5 min, put in Petri dishes and stored at 24°C or 4°C in a desiccator saturated with water vapour so as to avoid surface dehydration of the sample.	Papain treatment can prevent enzymatic browning of apple about as well as sulphite treatment at both room temperature and refrigerated temperatures. Ficin showed a notable ability to prevent enzymatic browning.	Taoukis *et al.*, 1989. International Patent no: WO 89/11227
3. Apple, (Washington Golden, Red Delicious) 4-5 mm slices	1. Sodium bisulphite 2. Sodium sulphhydrate 3. Sodium hydrosulphite 4. L-Cysteine 5. NAC 6. GSH (reduced) 7. Sodium salicylate 8. Mixed acids (a) 1% CA, 1% AA and 0.2% potassium sorbate; (b) 0.5% CA, 0.3% AA and 0.2% potassium sorbate.	Concentrations: 5, 10, 25 and 50 mM (adjusted to pH 7). Immersed for 1-2 min, placed in culture dishes (A values) or in plastic bags which were evacuated (B values).	NAC and GSH (reduced), applied at 25 or 50 mM concentration, appear as effective as sodium sulphite in preventing browning of apples. The mixed organic acids were effective only for a short period.	Molnar-Perl & Friedman, 1990.
4. Apple, (Granny Smith, Red Delicious) cubes, 1 cm^3	ι-, κ- and λ-carrageenan (0.5%) and CA (0.5%) either alone or in combination	Treatment time 10 min, covered and stored at 3°C for up to 10 days	Carrageenans or CA alone did not inhibit browning. The mixture of ι-, κ- or λ-carrageenan and CA delayed browning for up to 7 days with Granny Smith apple dice and for up to 3 days with Red Delicious. There appeared to be no significant difference in effectiveness of the 3 carrageenans.	Tong & Hicks, 1991.
5. Apple, (McIntosh/ Delicious) slices, 15 mm diameter x 15 mm thick	1. 1% solution (w/v) of papain, ficin and bromelain were prepared with deionized water 2. Papain solutions: 0.4, 0.6, 0.8, 1.0, 1.2, 1.4 and 1.6% 3. Buffered 1.0% papain with pH 5.4-7.0: a buffer solution of 0.1 M citric acid or 0.1 M sodium phosphate 4. AA: 0.5-2.0%, papain 0.5-2.0%, and their combinations	1. Treatment time 2 min. Slices were drained and placed in vented plastic boxes over water-saturated paper towels covered with plastic film to prevent moisture loss, stored at 22-25°C. 2. Treatment times 2 or 5 min, otherwise as mentioned above. 3 and 4. Treatment time 2 min and other procedures as mentioned above.	1. Papain inhibited browning of apple slices (12 h). Apple slices treated with ficin become grey instead of brown. Bromelain treatment rendered apple slices more red than white or brown. 2. Either 1.0% papain with a 2-min dip or 0.8% papain with a 5-min dip may provide adequate protection from browning for 12 h at room temperature. 3. No difference in inhibition of browning among papain solutions prepared with 2 buffers at different pH values. Apple slices treated with buffered papain solutions had less browning than those prepared with deionized water. 4. Apple slices dipped in the combined solution of 1% papain and 0.5% AA did not brown for 24 h at room temperature.	Luo, 1992.

Table 2. Browning inhibition methods studied for apples cont'd.

Treated material	Browning inhibitors (BI)	Other treatments and/or conditions	Results	Reference
6. Apple, (Red Delicious) sliced to obtain rings of 1 cm thickness	1. Distilled water (=control) 2. Canned pineapple juice (PJ) 3. Frozen concentrated pineapple juice (FCPJ), diluted to 12.8°Brix 4. Ion exchanged canned pineapple juice (IEPJ) 5. 0.7% AA 6. Frozen concentrated orange juice (OJ), diluted to 11.8°Brix 7. 0.7% EVER FRESH (EF) 8. 0.1% Sodium bisulphite	Treatment time 2 min with every BI. Storage either at 21°C or vacuum-packed in Cryovac bags and stored at 1°C.	AA treatment seemed to be as effective as PJ in inhibiting the browning of apple rings for at least the first 10 h. From 18 h to 48 h, sulphite, PJ and IEPJ were significantly better (p=0.05) inhibitors than the other treatments. There was no significant change in colour during the first 4 weeks. Sensory panel results indicated that sulphite, AA and PJ treated vacuum-packed rings rated lowest in browning.	Lozano-de-González *et al.*, 1993.
7. Apple, (Red Delicious) 1-cm thick slices	1. 0.02% (w/v) Hexylresorcinol + 0.25% (w/v) AA 2.1% (w/v) AAP + 0.25% (w/v) AA 3. 0.1% (w/v) Sodium sulphite + 0.25% (w/v) AA	In addition to the antibrowning agents, all sugar solutions included the general formulation of 0.2% CA, 0.15% sorbic acid and sucrose to make up a 52°Brix syrup. The general solution was the blank, and that formula plus 0.25% (w/v) AA was the control treatment. Treatment times 1, 3 or 10 h, at 30°C, packed in 2 mil thick plastic pouch, hermetically sealed under partial vacuum, stored up to 75 days in incubators at 25, 30, 35 or 45°C.	HR in combination with AA was an effective anti-browning agent that compared favourably to sodium sulphite at a storage temperature of 25°C. Antibrowning treatments were rendered ineffective when storage was > 35°C.	Monsalve-González *et al.*, 1993.
8. Apple, (Golden Delicious) slices	1. Pineapple juice 2. Sulphite 3. Hexylresorcinol	Packaging with or without vacuum.	The addition of pineapple juice to the apple slices improved colour and texture, and there was significant difference from the control for all treatments after 15 days' storage. No significant difference in colour was found for apple slices treated with sulphite or pineapple juice but both agents did better than HR.	Meza *et al.*, 1995.
9. Apple, (Delicious) 5-mm thick slices	Dipped in solutions containing 1. 4-Hexylresorcinol (HR): 0, 0.005, 0.01, 0.02 and 0.03% (w/v) alone or combined with 0.5% AA and/or 0.2% CaCl2 2. AA: 0.25, 0.5 and 0.75% with 0.01% HR and 0.2% CaCl2 3. 0.01% HR, 0.5% AA, and 0.2% CaCl2 4. AA 0.5%, CaCl2 0.2%, and HR 0.005 to 0.02%	1. Treatment time 10 min, packaged in 2 mil thick plastic pouches, hermetically sealed and stored at 4.4°C. 2. Treatment time 10 min 3. Treatment time 10 min and stored at 0.5°C. Slices were placed in Koch plastic pouches (AT), Ziploc vegetable bags with freshness vents (Veg) or Freshhold bags (FH) and sealed under ambient atmosphere, partial vacuum, or filled with N2. 4. Treatment time 2 or 5 min, packaged as no. 1, but partial vacuum, storage at 0.5°C	HR concentrations as low as 0.005% were effective in browning inhibition. AA synergistically enhanced browning inhibition. The browning inhibition of apple slices was improved and extended by vacuum packaging. Apple pieces treated with 0.01% HR, 0.5% AA and 0.2 $CaCl_2$ for 5 min, packaged under partial vacuum were stored at 0.5°C for 50 days with acceptable colour and texture.	Luo & Barbosa-Cánovas, 1995.
10. Apple, slices	A Maillard reaction product (MRP) prepared from 0.75 M histidine and glucose under alkaline condition and heated for 6 h at 95°C was used for apple slices.		A 5% solution of this MPR showed a stronger antibrowning effect than 0.5% ascorbic acid when used as a dipping solution for minimally processed apple slices.	Lee *et al.*, 1996.

Table 3. Browning inhibition methods studied for iceberg lettuce.

Treated material	Browning inhibitors (BI)	Other treatments and/or conditions	Results	References
Chopped lettuce	SPORIX ™ compound 1 part by weight, citric acid 1 part by weight, and water 200 parts by weight	Sole dip 1 min. Packaging in polyethylene bags, no vacuum.	After storage at refrigeration temperature (2-5°C), chopped lettuce maintains normal shelf life and marketable quality, in terms of normal colour, texture, taste and flavour, for 7 days	Gardner *et al.*, 1991. Patent 4,988,523
Iceberg lettuce, 6-mm pieces	-	Shredded lettuce was packed with a vacuum chamber system in 200-g bags. 80-µm polyethylene (PE) film (600 cm3 day-1 m-2 bar-1, 5°C) and 59-µm multilayer coextruded film (SL3) (1200 cm3 day-1 m-2 bar-1, 5°C) were used. Four treatments and codes were: 1. SL3-atm, SL3-bags, atmospheric air 2. PE-mvp, PE-bags, moderated vacuum packaging 3. SL3-80% O2/20% CO2 4. PE-80% O2/20% CO2 Stored at 5°C for 10 days. Sensory evaluations up to 17 days.	Shredded lettuce in PE-mvp bags had a high visual quality after 10 days. The optimal equilibrium atmosphere (2% O_2 and 7% CO_2) was obtained in these bags after a few days storage. Lettuce in PE-80/20 bags had an overall poor sensory quality after 10 days storage because of development of off-flavour and tissue softening. Poor visual quality soon occurred in SL3-atm bags because of browning, but no off-flavour developed during storage.	Heimdal *et al.*, 1995.
Iceberg lettuce, lettuce stems were cut with a knife in circular sections (3 cm diameter and 0.5 cm thickness) and lettuce heads with similar size.	1. AA 50 g/l 2. BHA 0.1 g/l 3. BHT 0.1 g/l 4. Cysteine 4 g/l 5. CA 100 g/l 6. EDTA 5 g/l 7. Resorcinol 0.1 g/l 8. Rutin 0.2 g/l 9. Catecol 0.1 g/l 10. Ficin 0.01 g/l 11. Ficin 0.1 g/l 12. Hydroquinone 0.1 g/l 13. Acetic acid 10, 50, 100 ml/l 14. CA 10, 50, 100 g/l 15. Gluconic acid 10, 50, 100 g/l 16. Lemon juice 17. Vinegar (containing 60 ml/l acetic acid)	Treatment time 5 s. 1. Treatments 1-17 stored at 20°C and 90 RH on Petri dishes. Colour was measured at 0, 3, 5, 8, 16 and 24 h with a Minolta Chromameter. 2. Acetic acid 10 and 50 ml/l and vinegar treated lettuces were wrapped with perforated polypropylene film, stored at 2°C for 7 days and, after that, at 13°C for 3 days to simulate a reasonable commercial handling.	In treatments 1-12 cysteine, CA, EDTA and resorcinol prevented browning better than others ($p<0.05$). All acids resulted in inhibition of lettuce browning, but best results were obtained with all acetic acid solutions and vinegar. Acetic acid solutions (pH 2.30-2.81) resulted in better browning inhibition than citric acid solutions (pH 1.67-2.25), although the pH was higher for acetic acid. Both vinegar and 50 ml/l acetic acid solutions could be very useful in preventing browning in lettuce cut stem during cold storage and commercial handling.	Castañer *et al.*, 1996.
Iceberg, Romaine, Butter, Green leaf, Red leaf; salad pieces	-	Air or controlled atmosphere containing 3% O_2 + 10% CO_2. Stored for 16 days at 5°C.	The quality of CA-stored iceberg salad pieces stored for up to 14 days was similar to that of salad pieces prepared from freshly harvested lettuce. The quality of minimally processed Romaine lettuce was detrimentally affected by a 7-day storage period.	López-Gálvez *et al.*, 1996.

Sulphydryl-containing amino acids like cysteine prevent brown pigment formation by reacting with quinone intermediates to form stable, colourless compounds (Dudley & Hotchkiss, 1989). Cysteine has been used as a browning inhibitor for potatoes, apples and iceberg lettuce (Molnar-Perl & Friedman, 1990; Castañer *et al.*, 1996) and it has also been used as an ingredient in a commercial browning inhibitor (Cherry & Singh, 1990). According to Gunes and Lee (1997), an L-cysteine (0.5%) and citric acid (2%) mixture prevented browning of potatoes effectively. Reduced glutathione and *N*-acetylcysteine are nearly as effective as sulphites in controlling browning in apple, potato, and fresh fruit juices (Molnar-Perl & Friedman, 1990).

Enzymatic methods

Protease enzymes were found to be effective browning inhibitors for apples and potatoes (Taoukis *et al.*, 1989; Labuza *et al.*, 1992; Luo, 1992) (see Tables 1 and 2). It is believed that an effective protease acts to hydrolyse and, therefore, inactivate the enzyme or enzymes responsible for enzymatic browning. Of the proteolytic enzymes tested so far mainly 3 plant proteases (ficin from figs, papain from papaya and bromelain from pineapple) proved to be effective. All 3 proteases are sulphydryl enzymes of broad specificity. According to Taoukis *et al.* (1989), ficin was as effective as sulphite for potatoes at 4°C, but slightly less effective than sulphite at 24°C. Papain was somewhat effective for potatoes at 4°C. Papain treatment can prevent enzymatic browning of apples about as well as sulphite treatment at both temperatures (4°C and 24°C).

Physical methods

Statistically valid evidence of the effectiveness of high-O_2 modified atmosphere packaging (MAP) was provided by Day (1997) with iceberg lettuce. This so-called 'oxygen shock' or 'gas shock' treatment has been found to be particularly effective at inhibiting enzymatic browning, preventing anaerobic fermentation reactions, and inhibiting aerobic and anaerobic microbial growth. It is hypothesized that high O_2 levels may cause substrate inhibition of PPO or, alternatively, high levels of colourless quinones subsequently formed may cause feedback production of PPO.

Oxygen concentrations in the atmosphere surrounding a product can be reduced by MAP. While this approach can delay browning, excessive reduction of oxygen will damage the product by inducing anaerobic metabolism, leading to breakdown and off-flavour formation.

A packaging atmosphere of 20% CO_2 and 80% N_2 with citric and ascorbic acids as browning inhibitors gave the best sensory quality of sliced potatoes after 7 days' storage. Oxygen concentrations in the package head space were less than 1.5% during a 7-day storage period (Laurila *et al.*, 1998). According to Ahvenainen *et al.* (1998), the quality retention of peeled potatoes was as good in vacuum as in gas (20% CO_2 + 80% O_2). Gunes and Lee (1997) showed that active modification of the atmosphere inside the package was necessary to extend the shelf-life of the potatoes but MAP alone did not prevent browning. Dipping treatment was essential in packaged potatoes.

A carbon monoxide (CO) gas atmosphere was found to inhibit mushroom PPO reversibly. Use of this compound in a modified-atmosphere packaging system would require measures to ensure the safety of packing plant workers.

High-pressure treatment of potatoes and apples at 800 MPa caused little browning but both foods took on a cooked appearance (Gomes & Ledward, 1996).

Other methods

One possible 'packaging' method for extending the postharvest storage life of lightly processed fruits and vegetables is the use of edible coatings, i.e. thin layers of material which can be eaten by the consumer as part of the whole food product. At least theoretically, coatings have the potential to reduce moisture loss, restrict ingress of oxygen, lower respiration, retard ethylene production, seal in flavour volatiles, and carry additives that retard discoloration and microbial growth (Baldwin *et al.*, 1995).

Antioxidants are added to edible coatings to protect against oxidative rancidity, degradation and discoloration. Nisperos-Carriedo *et al.* (1988) found that edible coatings reduced enzymatic browning in whole and sliced mushrooms. Further improvement in the antibrowning property of the coating was accomplished with the incorporation of an antioxidant and a chelator (1% ascorbic acid, 0.2% calcium disodium ethylene diaminetetraacetic acid). Various sulphated polysaccharides, including carrageenans, amylose sulphate and xylan sulphate, were found to be effective as browning inhibitors with diced apple (Tong & Hicks, 1991). Use of Nature Seal™ 1020, a cellulose-based edible coating, as a carrier of antioxidants, acidulants and preservatives prolonged the storage life of cut apple and potato by about one week when stored in overwrapped trays at 4°C. Ascorbic acid delayed browning more effectively when applied in an edible coating than in an aqueous solution (Baldwin *et al.*, 1996).

It is expected that a biological preservation method may enjoy better consumer acceptance than preservation methods that use traditional chemical preservatives (Schillinger *et al.*, 1996). Lactic acid bacteria (LAB) produce a variety of low molecular mass compounds including acids, alcohols, carbon dioxide, diacetyl, hydrogen peroxide and other metabolites. Bacteriocin-producing LAB show potential for minimally processed foods (Schillinger *et al.*, 1996). Hurdle technology using natural preservatives, e.g. inhibitors produced by LAB, may also work as browning inhibitors. The matching of correct processing methods and ingredients to each other should be applied to a greater extent in minimal processing of produce.

Measuring browning

In most cases, browning is measured (Tables 1, 2 and 3) by using different spectrophotometers or colorimeters, such as the Hunterlab, Gardner or Minolta instruments. In some cases the appearance of the product is evaluated by sensory panels.

It seems that the importance of L, a and b values depends on the foodstuff examined. In the $L^*a^*b^*$ colour space, L is the intensity, a the position on the green (-) to red (+) axis and b the position on the blue (-) to yellow (+) axis. For browning estimation, the L value has been considered as one of the best colour indices and is frequently used (Sapers & Douglas, 1987; Sapers *et al.*, 1989). According to Luo (1992), the L value

alone is not adequate and the use of both *a* and *b* values is necessary if the research involves the change of hue and chroma. Cherry and Singh (1990) found that the difference in *L* values (measured with the Hunterlab Colorimeter) between naturally white and blackened potatoes has a value of about 30, and a difference in *L* values of 3 units is significant and detectable visually. Visual observation of the pieces by 4 expert judges indicated that when a normalized $\Delta L/L_0 \times 100$ value, measured with a Minolta Chromameter, reached 2.5 for apple slices and 3.0 for potato slices, the colour could not be distinguished from the initial colour of the slices (ΔL is the change in *L* value at any time and L_0 is the initial *L* measurement). Slight browning, subjectively considered to be just at the point of unacceptability, corresponded to a normalized $\Delta L/L_0 \times 100$ value of about 4.0 for apple and 5.0 for potato. Extremely brown apple slices had a normalized $\Delta L/L_0 \times 100$ value of about 15.0 (Labuza *et al.*, 1992). According to Langdon (1987), an *E* value of 3 or less, measured with a Gardner Colorimeter, is considered to be a non-perceptible colour difference. The *E* value is the total colour difference between fresh potatoes and those that are treated and packaged. López-Gálvez *et al.* (1996) found that the *a* value was most highly correlated with visual evaluations for iceberg lettuce. More information about *L*, *a* and *b* values for different vegetables and fruits and their correlation with visual observations is needed.

Development needs and future prospects

It is probable that, in the future, vegetables and fruits intended for minimal processing will be cultivated under specified controlled conditions, and furthermore, that plant geneticists will develop selected and created cultivars or hybrids adapted to the specific requirements of minimal processing (Varoquaux & Wiley, 1994: Martinez & Whitaker, 1995). According to Watson (1995), a large number of transgenic potato lines containing the antisense PPO gene have been generated and these exhibit low levels of PPO activity ranging from 1 to 10% of normal levels.

In most research only the prevention of browning has been studied. The effect of browning inhibitors on the sensory quality of products has not been examined. Sensory attributes such as appearance, flavour, odour and texture are also important factors affecting consumer acceptability. These attributes must be taken into account when a browning prevention method is selected.

A characteristic feature in minimal processing is an integrated approach, where raw material, handling, processing, packaging and distribution must be properly considered to make shelf-life extension possible. The unit operations, such as peelers and shredders, need further development to make them gentler. There is no sense in disturbing the quality of produce by rough treatment during processing, and afterwards patching it up with preservatives (Ahvenainen, 1996).

The effectiveness of non-sulphite dips at inhibiting discoloration of different prepared produce under various MAP conditions is currently under study in an EU FAIR CT96-1104 project "Novel high oxygen and noble gas modified atmosphere packaging (MAP) for extending the quality shelf-life of fresh prepared produce". This project, coordinated by Brian Day at Campden & Chorleywood Food Research Association (UK), started in September 1996 and will last till September 1999. In this project the inhibition of discoloration of minimally processed vegetables and fruit is being studied at VTT Biotechnology and Food Research in Finland, at the University of Limerick in Ireland, and at CCFRA. VTT is carrying out research on potatoes, Limerick University on shredded iceberg lettuce, sliced apples and prepared potatoes, and CCFRA is studying the effects of suitable dip formulations on various prepared produce.

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