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Enzymatic browning and its control in fresh-cut apple

In last few decades, the market for fresh-cut fruits and vegetables has grown rapidly as a result of their freshness, convenience and human health benefits. However, fresh fruits and vegetables deteriorate very rapidly after processing, especially cut-surface browning resulting from wound induced physiological and biochemical changes. Browning of fresh-cut apples during post-harvest handling and processing degrades the sensory properties and nutritional value and discourages consumer purchase. Consequently, enzymatic browning results in significant economic losses for the fresh-cut industry. In respect of above background, the application of anti-browning agents is one of the most effective methods for controlling the enzymatic browning reaction in fresh-cut apple.

THE fresh-cut industry is one of the growing food industries in India as a result of consumer demands for fresh, healthy and convenient products. Fresh cut apples are valued for having various functional properties and also desired as a convenient snack for catering services to salad-bars, schools and company cafeterias. Minimally processed fresh-cut fruits make a significant portion of international food markets. In addition, fresh-cut products also offer other advantages over bulk produce in terms of waste management, shipping and in-store labour cost reduction etc. Minimal processing includes washing, cutting, drying and packaging so that the finished product is ready to eat.

Enzymatic browning is the most limiting factor for determining the shelf life of minimally processed apples. It is an extensive spreading colour reaction take place in fresh-cut apples which involves the interaction of oxygen, phenolic compounds and polyphenol oxidases. Browning reaction is normally commenced by the enzymatic oxidation of monophenols into diphenols and diphenols into quinones which undergo further non-enzymatic polymerisation leading to the formation of pigments. Enzymatic browning is deleterious to quality maintenance of the fresh-cut apple industry. Browning not only has a negative impact on their appearance but also may diminish other sensory qualities including firmness, taste, odour and as well as nutritional quality. When fruit tissues are injured by slicing, the mixture of polyphenol oxidases and phenolic compounds released consequently result in rapid browning reactions. Enzymatic browning of fresh-cut apples can lead to considerable economic losses, especially if browning take place early in the product's projected shelf life but after the costs of processing, packaging and storage have been incurred. The understanding of browning and its control from harvesting to consumption is therefore important for reducing losses and maintaining the economic profitability of the apple processors. In order to meet consumer demand for convenient and fresh-like quality of minimally processed apples and to provide additional technical information to Indian apple growers and processors for value added product, we have been working on minimal processing of apple slices.

Recent approaches to control enzymatic browning in fresh-cut apple

The control of enzymatic browning is one of the most important issues in fresh-cut apple industry. Various approaches to inhibit browning of fresh-cut apples have been reported including a wide variety of chemical compounds, edible coatings, modified atmosphere packaging and temperature control which are discussed below.

Browning inhibitors

A dip treatment after slicing is the most common way to control browning phenomena in fresh-cut apples. A range of treatments have been applied to extend the shelf life of fresh-cut apples including use of natural browning inhibitors, salt and chemical treatments, edible coating agents and reduced oxygen atmospheres. A key approach used to avoid browning in apples has been the use of reducing agents, often with the addition of calcium chloride, in combination with modified atmospheres and low temperature storage. Calcium salts, particularly $CaCl_2$, are used as firming agents in a wide variety of whole, peeled and fresh-cut fruits.

Ascorbate and calcium

The most commonly used anti-browning agent is ascorbic acid which is recognized as a GRAS substance

by the Food and Drug Administration for its use to control browning of minimally processed apples. Ascorbic acid is used to prevent polyphenol oxidases enzyme activity through its ability to reduce the o-quinones back to their phenolic substrates. Ascorbic acid has long been applied in combination with organic acids and calcium salts to control browning of minimally processed apple slices. A formulation containing ascorbic acid and calcium acts to prevent cell and membrane breakdown and also modulates polyphenol oxidase activity in ruptured cells where loss of compartmentalization has take place already. For instance, 4-hexylresorcinol in combination with ascorbic acid had a significant effect on maintaining the colour of fresh-cut apples.

Thiol-containing compounds

The N-acetylcysteine and glutathione are some thiol-containing natural substances having antioxidant properties and have been applied as browning inhibitors to prevent discoloration on fresh-cut apples. These thiol-containing anti-browning compounds react with o-quinones formed during the initial phase of browning reactions to yield colourless products or to reduce o-quinones to o-diphenols.

Carboxylic acids

Carboxylic acids have been widely used commercially due to their anti-browning activity. Citric acid exerts a double inhibitory effect by reducing *p*H and chelating copper in the active site of polyphenol oxidase and therefore, inactivating the enzyme. Acidulants are not often used alone because it is difficult to achieve efficient browning inhibition, and combination with a chemical reductant may have a major effect.

Resorcinols

Among several resorcinol derivatives, 4-hexylresorcinol has been proved to be effective in controlling browning on fresh-cut fruit such as apples and pears. 4-hexylresorcinol (4-HR) has a structural resemblance to phenol substrates and could have a competitive inhibitory effect on polyphenol oxidase activity. Hence, 4-hexylresorcinol may specifically interact with polyphenol oxidase, and render it unable to catalyze the enzymatic reaction. Its applicability on fresh-cut fruit has been proven especially when used in combination with reducing agents. Some combinations have been proven to extend the storage life of fresh-cut produce. A mixture of 0.01% 4-hexylresorcinol + 0.5% ascorbic acid + 0.02% calcium chloride maintained freshness of 'Royal Delicious' apple wedges for one week at 5 + 2°C.

Modified atmosphere packaging

The rapid growth of the packaged fresh-cut fruits industry has been enabled largely by the development of modified atmospheric packaging technology. With modified atmospheric packaging the desired balance of O_2 and CO_2 is created through the control of gases transmission of the packaging film and the respiration rate of the produce. Modified atmospheres can retard the browning reaction. Among other benefits the use of modified atmospheres delayed senescence and consequently enhanced storage life of fresh-cut apples.

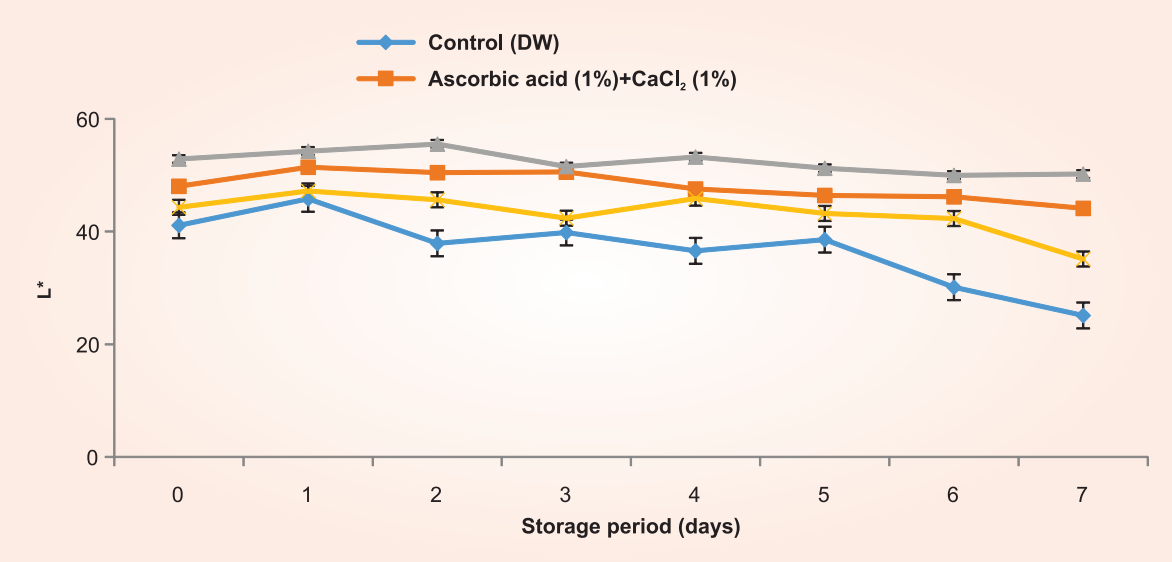
Edible coatings

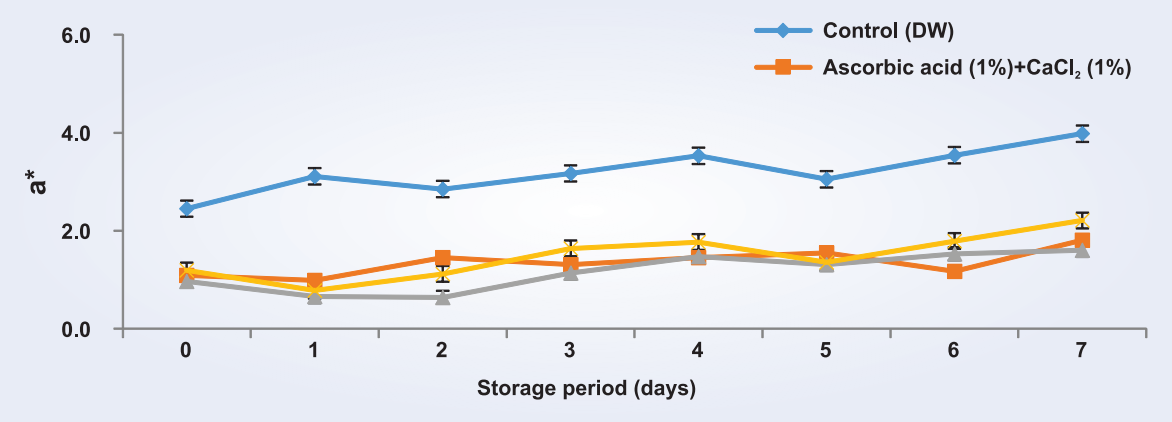
In modern era, the edible coatings are receiving significance as methods that can preserve the quality of fresh-cut apples. It can serve as semi-permeable barriers come up with to enhance shelf-life by reducing moisture and solute migration, gas exchange, respiration and oxidative reaction rates as well as suppressing physiological disorders on fresh-cut apples. Recently, some investigations have proposed the use of edible coatings in combination with anti-browning agents to improve the colour preservation of fresh-cut apples. Through modification of oxygen, carbon dioxide and ethylene transmission, the edible coating has the ability to inhibit the moisture loss, form a barrier to oxygen and control the release of anti-browning compounds on the surface of cut tissues. Edible coatings may be used in combination with other preservation techniques such as low temperature and suitable packaging to achieve browning control in fresh-cut apples. The edible coatings in combination with anti-browning agents (4-HR, ascorbic acid and citric acid) effectively prolonged the shelf-life of the minimally processed apple slices by 1 week when stored at 5 ± 2 °C.

In general, chemicals used to prevent or control enzymatic browning are used in solutions, frequently as formulations containing one or more compounds, which are used for dipping the fruit pieces.

Apple slicer

In general, increased enzymatic browning of fresh-cut apple wedges during storage was accompanied by an increase in a* and a decrease in L* values. The lowest L* and the highest a* values were obtained in control samples dipped in water. The solutions containing anti-browning agents significantly decreased the loss of lightness (L*) of apple wedges. Fresh-cut apple wedges dipping in the antioxidant aqueous solution helped maintain L* values during storage, although the most effective formulation was that containing 4-HR to maintain high L* angle values in apples over 7 storage days at 5 + 2 °C. Overall, the combined application of anti-browning agents maintained





Hunter L* and a* values of apple wedges after seven days of storage. Bars on graph represent standard error.

lower a* and higher L* values than the alone antioxidant aqueous solution, which indicates its potential to control the enzymatic browning of fresh-cut apples.

SUMMARY

Enzymatic browning is an economically important physiological problem that impairs the sensory qualities and discourages consumer purchase of fresh-cut apples. Control of browning on fresh-cut apples has been the focus of extensive research and many technologies have been explored with successful results. Research on effective combinations of various chemical compounds above needs to be undertaken since no single treatment can effectively enhance the shelf life of fresh-cut apple wedges while controlling browning and preserving the quality and safety for consumers.

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