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Commercialisation of Chemistry Education through Browning of Some Foods to Enhance Their Economic Values

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Abstract

All foods are chemical compounds that are beneficial to living organisms. The chemistry of food involves complex reactions from biosynthesis to the utilization in the body of organism. Many stages and steps are involved in the preparation of food for human consumption. This paper discusses the browning reactions of some foods using chemistry education to enhance the physiological content and physical texture of these foods towards increasing their economic values. It explains polyphenol oxidase and mechanism of enzymatic browning in yam and milk, effect of Maillard reaction, browning during bread making, beneficial effects and detrimental effects of browning reactions and control of enzymatic and non-enzymatic browning. It concludes by suggesting some precautions such as antioxidant effect, bleaching effect, pH- value among many others which are to be taken to reduce the rate of browning to make these foods maintain their economic values for commercial purposes.

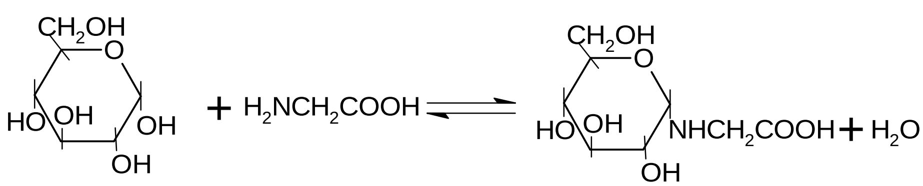
Key words: Chemistry Education, Food Browning, Economic Value.

The application of heat in sterilization, cooking and dehydration processes can cause many complex reactions to occur in food materials (Fennema, 1996). These reactions influence food colour, flavour and texture, which may be desirable or undesirable, and are important to the food processors, so as to add value for commercial purposes. Acceptable browning occurs in baked foods, beer, molasses, coffee, breakfast cereals, many snacks, nuts and meat. While browning is undesirable in some other food materials, such as fruits, vegetables, some tubers (cassava, potatoes) among others (Van-Boekel, 2008). Browning reactions are recognized in food science and technology. The most common type is the carbonyl-amino reactions, which includes the reactions of aldehydes, ketones, and reducing sugars with amines, amino acids, peptides and proteins known as Maillard reaction which is simply a reaction between glucose and glycine (Jongen &Van-Boekel, 2001). The French chemist Maillard was the first to study the condensation of sugars with amino acids reported in 1912 when mixtures of amino acids and sugars were heated and brown substances were formed (Frank, 1983). Since then, the Maillard reaction has been considered as the major cause of non-enzymatic browning in foods and numerous studies had been conducted to prove this connection and the following steps were identified (Mendoza, Dejmek & Aguilera, 2007).

(a) Sugar-amino condensation.
(b) Fission and degradation.
(c) Dehydration of rearrangement products.
(d) Polymerization into pigments.
(e) Rearrangement of condensation products.

Condensation of Sugars with Amino Compounds

This is a reaction that occurs when sugars react with primary and secondary amines to form *glycosylamines*. Similar condensation reactions occur with free amino acids and free amino groups of peptides and proteins (Mondal & Datta, 2008).



Degradation and Fission Reactions

Another non-enzymatic browning which takes place during carbon (iv) oxide production in the course of amine- sugar interaction (Bark, 1980). The formation of low- molecular weight intermediates such as pyrualdehyde and diacetyl in sugar-amino acid mixtures are from the fragmentation of the carbohydrate moiety, or the amino acid or both. In the presence of certain dicarbonylic compounds, amino acids are known to undergo decarboxylation (Chopra & Paneser, 2013).

$$R_1-\overset{O}{\overset{\|}{C}}-\overset{O}{\overset{\|}{C}}-R_2 + R_3-CH(NH_2)COOH \longrightarrow R_1-C(NH_2)=C(OH)-R_2 + R_3CHO + CO_2$$

Dehydration of Arrangement Products

This type of reaction called caramelization is when sugars are treated under anhydrous conditions with heat, or at high concentration with dilute acid, which begins with the formation of anhydro sugars (sugar without water) (Mundt & Wedzicha, 2007). At high temperature sugar caramelization occurs when minimal amounts of acidic and basic catalysts are used, and these are usually present in saps and syrups (Wahlby & Skjoldebrand, 2002). Practical caramelisation reactions are conducted with different catalysts to provide either flavouring or colouring caramel for food use in soft drinks like malt and beer (brown colour). This occurs when solutions of reducing sugars are heated and the chemical reactions involved are enolisation, isomerisation, dehydration and fragmentation (Fennema, 1996).

1. **Polymerisation reactions result in brown pigment formation**

This reaction is used in the manufacture of caramel colouring for use in beverages, it takes place when glucose syrup is treated with dilute tetraoxosulphate (vi) acid, partially neutralized with ammonia, then heated in the presence of sulphite at pH 4 (Hadiyanto, Asselman, Van-Straten, Boom, Esveld & Van-Boxtel, 2007). Many products of sugar caramelization have been identified and their contribution to colour and flavour are being evaluated which add value to food products. The caramel-like part of browned aromas seems to consist mainly of oxygen heterocyclics (Keskin, Sumnu & Sahin, 2004).

2. Rearrangement of condensation products

The thermal decomposition of sugars gives rise to furans, furanones, pyrones, lactones, aldehydes, ketones, acids and esters. Most of these compounds have desirable flavours at minimal concentration (Frank, 1983). However, Caramel flavour is not acceptable in some foods such as orange juice, dehydrated potato, dehydrated ice cream mixes, and dried milks and excessive caramelization in maple syrup is undesirable (Mendoza, Dejmek & Aguilera, 2007). This paper discusses the optimum browning in some food to enhance their economic values.

Browning of Some Food Products

The browning frequently encountered by the food processor is the group of oxidative reactions which converts ascorbic acid and polyphenolic compounds (Bark, 1980; Frank, 1983). This type of reaction is Enzymatic Browning and frequently occurs in many types of fresh vegetables, fruits and some tubers (yams, potatoes). The end product is the brown pigment called melanin (Ameur, Trystram & Birlouez-Aragon, 2006). Enzymatic browning is one of the most important color reactions, which affect fruits, vegetables, sea foods among others, and it is catalyzed by the enzyme polyphenol oxidase, phenolase, monophenol oxidase, diphenol oxidase and tyrosinase (Fennema, 1996). It can be defined as a process involving polyphenol oxidase or other enzymes that create melanins, resulting in a brown color, which is observed on the cut surfaces of light coloured fruits and vegetables such as apples, bananas and potatoes. It is due to the oxidation of phenols to orthoquinones, which in turn rapidly polymerize to form melanin (the brown pigment). When the substrate is a phenol, it is first hydroxylated through hydroxylation into orthodiphenol in the presence of enzyme and then oxidized to orthoquinone which is undesirable (Bark, 1980; Frank, 1983; Chopra & Paneser, 2013).

Phenolic compounds are widely distributed in the plant kingdom and they contain aromatic rings bearing one or more hydroxyl groups, together with a number of other substituents, they are secondary metabolites. Plants provide nearly all the phenols found in higher animals, since higher animals are incapable of synthesizing compounds with benzonoid rings from aliphatic precursors. The polyphenolic composition of fruits varies in accordance with species, cultivar, degree or stages of ripening and environmental conditions. Phenolics also contribute to colour, astringency, bitterness, and flavour in fruits, vegetables, tubers and many others (Frank, 1983). Phenolic compounds occurring in food materials are mostly of the flavonoid type. Tyrosine is the major phenol substrate for phenolase action in foods. Of all the naturally occurring flavonoid compounds, anthocyanidins, flavonols, and cinnamic acid derivatives occur most frequently in foods. Catechins, cinnamic acid, esters, 3,4-dihydroxy phenylalanine (DOPA), and tyrosine are the most important natural substrates of polyphenol oxidase in fruits and vegetables (Table 1). Catechins are structurally related to other flavonoids having the basic nucleus of 1,3-diphenylpropane (Bark, 1980; Frank, 1983; Fennema, 1996).

Table 1: Phenolic Substrates in Some Foods, Fruits and Vegetables

Apple	Chlorogenic acid, catehol, catechin, caffeic acid, 3-4 dihydroxyphenylalanine (DOPA), 3,4 - dihydroxy benzoic acid, p-cresol, 4-methyl catechol, p- coumaric acid, flavonol glycosides.
Apricot I	Iso-chlorogenic acid, caffeic acid, 4-methyl catechol, chlorogenic acid, catechin, epicatechin, pyrogallol, catechol, flavonol, p-coumaric acid derivatives.
Banana	3,4=-dihydroxyphenylethylamine (Dopamine), leucodelphinidin, leucocyanidin.
Cocao	Catechins, leucoanthocyanidins, anthocyanins, complex tannins.
Coffee beans	Chlorogenic acid, caffeic acid.
Eggplant	Chlorogenic acid, caffiec acid, coumaric acid, cirmamic acid derivatives.
Grape	Catechin, chlorogenic acid, catechol, caffeic acid, DOPA, tannins, flavonols, protocatechuic acid, resorchinol, hydroquinone, phenol.
Lettuce	Tyrosine, caffeic acid, chlorogenic acid derivatives.
Mango	Dopamine - HCL, 4-methyl catechol, caffeic acid, catehol, catechin, chlorogenic acid, tyrosine, DOPA, p-cresol.
Mushroom	Tyrosine, catechol, DOPA, dopamine, adrenaline, noradrenaline.
Peach	Chlorogenic acid, pyrogallol, 4-methyl catechol, catechol, caffeic acid, gallic acid, catechin, Dopamine.

Pear	Chlorogenic acid, catechol, caffeic acid, DOPA, 3,4-dihydroxy benzoic acid, p-cresol.
Plum	Chlorogenic acid, catechin, caffeic acid, catechol DOPA.
Potato	Chlorogenic acid, caffeic acid, catechol, DOPA, p-cresol, p-hydroxyphenyl propionic acid, p-hydroxyphenyl pyruvic acid, m-cresol.
Sweet potato	Chlorogenic acid, caffeic acid.

Browning Reactions of Yams

One relative successful procedure for improving the postharvest storage of White yam (*Dioscorea rotundata*) tubers involves processing it into flour. This consists of peeling off the outer covering (peels or bark), cubing (slicing into chips), soaking in warm water or parboil for few minutes, drying and milling into flour. Unfortunately, consumer acceptability and the shelf-life of the flour are adversely affected by the inability of the flour to retain the typical White colour of yam which is highly desired by consumers (Frank, 1983). Colour changes in freshly damaged plant materials have been attributed to the activity of polyphenol oxidase, which catalyses the oxidation of polyphenols to orthoquinones and peroxidase that catalyses the oxidation of a number of aromatic compounds which has been associated with darkening in fresh and processed vegetables and fruits making these food materials to lose their economic values and acceptability (Bark, 1980; Chopra & Paneser, 2013).

Browning Reactions in Milk

Milk is usually subjected to heat treatment to ensure microbiological safety before retail and consumption. The major types of heat treatment include; low temperature long time (63°C for 30 minutes) pasteurization, high temperature short time (72°C for 15 seconds) pasteurization, and ultra-high temperature treatment. In all types of heat treatment, the Maillard reaction (Non- enzymatic reaction and caramelization) occurs in milk and sterilization of Milk which may have the temperature of 150°C for about 30 minutes. This is where most of the Maillard reaction and caramelization take place (Yam & Papadakis, 2004). The Maillard reaction (non-enzymatic glycation) is a chemical reaction between amino group and carbonyl group; it is extremely a complex reaction that usually takes place during food processing or storage. In the case of milk, lactose reacts with the free amino acid side chains of milk proteins (mainly s-amino group of lysine residue) to proceed to early, intermediate, and advanced stages of Maillard reaction and forms enormous kinds of Maillard reaction products. The reactions of lactose and milk proteins have been frequently investigated and the formations of various Maillard reaction products in milk during heat treatment have been demonstrated (Broyart, Trystram & Duquenoy, 1998).

In general, it is a reaction that progresses to the 3-deoxyosone or l-deoxyosone route depending on the reaction pH. In the case of disaccharides such as lactose, there is a third reaction route which produces the 4-deoxyosone. A main carbohydrate in milk is lactose. Thus, the Maillard reaction in milk results in the formation of melanoidins (browning compounds).

Effect of the Maillard (non-enzymatic) Reaction on Milk Proteins

The Maillard reaction shows some desirable effects on milk proteins such as bioavailability, solubility, foaming property, emulsifying property, and heating stability (Dolan, 2003). In addition, the formation of flavor compounds and browning compounds is caused as the consequences of this reaction between lactose and milk proteins making milk more palatable and acceptable (Frank, 1983). The effect of Maillard reaction on the bioavailability of milk proteins, several studies have verified its acceptability (Ramirez, Guerra & Villanova, 2000; Chopra & Paneser, 2013). Generally, in the Maillard reaction in milk, lactose mainly reacts with e-amino group of lysine residue of milk proteins. Thus, the lysine loss by the Maillard reaction increases with a severity of heat treatment (Shibukawa, Sugiyama & Yano, 1989). The modified lysine cannot be available as a nutrient because the steam injection process (direct heating) generated 3.6% (120 °C for 400 sec.) and 6.8% (130 °C for 290 sec.) of the blocked lysine in whole milk. The indirect heating at 115°C for 10 to 40 minutes increased the modified lysine from ll.0 to l3.0%, which revealed that the lysine residues in skim milk powder were more susceptible to heating than those in skim milk (Therdthai, Zhou & Adamczak, 2002). Maillard reaction is responsible for the solubility loss in milk protein concentrate powder which extends the shelf life (Fennema, 1996). It was also reported that the glycated -3-lactoglobulin was more stable at acidic pH and more stable against heating. The glycation of β-lactoglobulin, moreover, could improve its foaming and emulsifying properties. These results suggested the usefulness of Maillard reaction to enhance milk proteins to have different properties and thus increases its economic value (Bark, 1980).

Browning during Bread Making

Bread baking can be defined as the process which transforms a dough basically made of flour, water and leavening agents into a high quality product with unique sensorial features. In particular, French or White bread is the most popular type of bread, and is distinguished for having a crunchy and yellow-gold crust, beyond other features (i.e. a sponge and light crumb with soft texture and intermediate moisture, and a typical flavour). In general, the aspect and colour of some food surface is the first quality parameter evaluated by consumers and is critical in the acceptance of the product, since it is associated with flavour and level of satisfaction (Pedreschi, Leon, Mery, & Moyano, 2006). Therefore, predicting and controlling the development of crust colour are very important issues for the bread making industry. The formation of the yellow-gold colour often called browning is due to non-enzymatic chemical reactions which produce coloured compounds during bread baking, specifically, the Maillard reaction and caramelization. Maillard browning products (melanoidins) are formed when reducing sugars and amino acids, proteins, and/or other nitrogen-containing compounds are heated together, such as in bread crusts (Fennema, 1996). In some foods, Maillard reaction is associated to a decrease of digestibility and possible formation of toxic and mutagenic compounds as well as the formation of antioxidative products (Jongen, & van-Boekel, 2001). Caramelization is a term for describing complex group of reactions due to direct heating of carbohydrates, in particular sucrose and reducing sugars (Fennema, 1996), which occurs in some systems like bread containing reducing sugars and amino groups when heated, caramelization and the Maillard reaction may take place simultaneously (Keskin, Sumnu & Sahin, 2004) both reactions depend on temperature, water activity and pH (Purlis & Salvadori, 2007). So, bearing in mind that bread baking is a process where simultaneous heat and mass transfer occurs (Purlis & Salvadori, 2007). The proposed model that follow the first-order kinetics and temperature dependent, was then applied to predict crust browning during bread baking at 200 and 250 ^{O}C; results were only acceptable at 250 ^{O}C. Ramirez & Villanova (2000) showed that development of browning can be evaluated effectively from colour measurement during baking and is exponentially correlated with baking time. In addition, crust browning is mainly controlled by temperature (Wahlby & Skjoldebrand, 2002). More recently, a brownness model was proposed by assuming an exponential relation between the concentration of melanoidins (produced by Maillard reaction) and colour development at bread surface during baking (Hadiyanto, Asselman, Van-Straten, Boom, Esveld & Van-Boxtel, 2007). Also, a simple model depending on the weight loss of bread during baking and the oven temperature is available (Purlis & Salvadori, 2007).

Browning during baking of biscuits has also been studied, as Shibukawa, Sugiyama, and Yano (1989) demonstrated that colour development depends only on temperature, and a first-order kinetic model, dependent on average temperature and moisture content, was developed to predict lightness variation of cracker surface during baking (Broyart, Trystram, & Duquenoy, 1998). More recently, it was observed that accumulation of 5-hydroxymethyl- 2- furfural (HMF) follows first-order kinetics during baking, and is highly dependent on the water activity, which must reach levels lower than 0.4 for allowing a significant formation of HMF (Ameur, Trystram, & Birlouez-Aragon, 2006). Conversely, Mundt and Wedzicha (2007) reported that water activity in the range 0.04 – 0.l5 has no influence on the rate of browning in the baking of biscuits. So far, it has been well demonstrated that development of browning during bread baking is only dependent on temperature and is caused by a group of complex reactions. Then, colour formation is usually simplified by assuming a general mechanism of browning or else neglecting caramelization to bring out the acceptable or desirable products that will be marketable (Zanoni, Peri & Pierucci, 1993).

Beneficial Effects of Browning Reactions

i. Bread produced during browning has a golden brown colour that is appealing to the eyes, also in browning of flour for sauces in hotels and restaurants (Yam & Papadakis, 2004).

ii. Foods produced have pleasant flavours (meat-like flavours) also pleasant flavour of coffee. Some of the flavour of Maillard (non-enzymatic) reactions include carbonyls, pyrroles, pyrazines, oxazoles, thiazoles, pyridines and imidazoles (Chopra & Paneser, 2013).

iii. Food produced has pleasant aroma and taste.

iv. Pleasant colour of tea, coffee, milk, biscuits among others.

Detrimental Effects of Browning Reactions

i. There is off colour in browning of yams that may not be appealing to the eye as seen in yam flour (enzymatic reaction), black colour of fruits and vegetables

ii. During sterilization of milk, there is loss of vitamins such as vitamin Bl, B2, B6 and many other valuable nutrients that may not be accessed due to high temperature.

iii. There is loss of amino acids during Maillard reaction such as lysine an essential amino acid needed for the synthesis of collagen used for binding cells and tissues. Lysine is the main amino acid in collagen which plays a role in calcium absorption, building of muscle protein and body producing hormones, enzymes and anti-bodies. It is also a precursor for bio synthesis of carnitine which plays a role in β- oxidating (Bark, 1980; Frank, 1984; Fennema, 1996).

Techniques for Browning

The techniques for control of enzymatic browning generally include the removal of one or more of the essential components (oxygen, enzyme, copper, or substrate) from the reaction. It can be achieved through the following ways:

i. Oxygen plays an important role in enzymatic browning and browning occurs rapidly upon exposure to oxygen. Elimination of oxygen from the cut surface of fruits or vegetables, some tubers among others greatly retards the browning reaction. The exclusion of oxygen can be carried by immersing in water, syrup, brine, or by vacuum treatment (Frank, 1983), which will minimize the chemical reactions and make the food have its economic values.

ii. The copper prosthetic group of polyphenol oxidases is essential for the enzymatic browning reaction to occur. For the removal of copper, chelating agents have been found effective (Fennema, 1996).

iii. Heat treatments such as steam blanching are effectively used for the inactivation of the polyphenol oxidases for the control of browning in fruits and vegetables to be canned or frozen. However, heat treatments are not practically applicable in the storage of fresh produce (Chopra & Paneser, 2013).

iv. Chemical modification of phenolic substrates such as caffeic acid, protocatechuic acid, chlorogenic acid, and tyrosine can however prevent their oxidation (Frank, 1983).

v. Certain chemical compounds react with the products of polyphenol oxidase activity and inhibit the formation of the coloured compounds produced in the secondary reaction steps (Bark, 1980).

Apart from the above, relatively new techniques, such as the use of killer enzymes, naturally occurring enzyme inhibitors and ionizing radiation, have been explored as alternatives to heat treatment and the health risks associated with certain chemical treatments (Chopra & Paneser, 2013).

Control of Non-enzymatic Browning (Maillard Reaction)

Maillard reaction is influenced by nature of reaction components and other reaction conditions. Most of these conditions are interdependent and can be controlled.

Nature of Sugars:

The nature of sugars in Maillard reaction determines the reactivity. Reactivity is related to their conformational stability or to the amount of open chain structure present in solution. Foods, which are rich in reducing sugars are more reactive. However, non-reducing disaccharides only react after hydrolysis takes place. Pentoses (five –carbon) are more reactive than hexoses (six-carbon), and hexoses more than reducing disaccharides. Among the aldohexoses, mannose is more reactive than galactose, which is more reactive than glucose (Fennema, 1996).

Type of Amino Acid:

Glycine is the most reactive in the amino acid series. Longer and more complex substituent groups reduce the rate of browning. Browning rate increases with increasing chain length in the co-amino acid series. Orinithine browns more rapidly than lysine. In proteins, particular sites of the molecule may react faster than others. The s-amino group of lysine in proteins is particularly susceptible to attack by aldoses and ketoses (Bark, 1980).

Temperature

The increase in temperature results in rapid increase in the rate of browning. Besides reaction rate, temperature may also change the pattern of the reaction. In model systems, the rate of browning increases two to three times for each 10°C rise in temperature. The increase may be even 5-10 times for each 10°C rise in foods containing fructose. The rate may be even more rapid at high sugar concentration. The composition of the pigment formed is also affected by temperature. The carbon content of the pigment increases at higher temperatures, and more pigment is formed per mole of carbon dioxide released. Color intensity of the pigment increases with increasing temperature (Bark, 1980; Frank, 1983; Fennema, 1996).

pH Value
The initial pH or presence of a buffer has an important effect on Maillard reaction. The decrease in pH slows the browning reaction. Maillard reaction can be said to be self inhibitory since the pH decreases with the loss of the basic amino group. The effect of pH on the browning reaction is highly dependent on moisture content. At low water levels with pH greater than 6, Maillard reaction is predominant, however when large amount of water is present caramelization takes place (Fennema, 1996).

Moisture Content
Moisture content is an important factor, which affects the rate of Maillard reaction. Browning occurs at low temperatures and intermediate moisture content; the rate increases with increasing water content. Due to limited diffusion, the rate is extremely low below glass transition temperature. The affect of moisture is also interdependent with pH of system (Fennema, 1996; Chopra & Paneser, 2013).
Besides the above factors, this reaction is also influenced by oxygen, metals, phosphates, sulphur dioxide,
and other inhibitors (Chopra & Paneser, 2013).

Factors Affecting Browning of Some Foods
The rate of non-enzymatic browning is strongly influenced by conditions such as temperature, pH value, moisture content, presence of accelerators or inhibitors.

a. **Effect of temperature**: The rate of browning increases with temperature regardless of the mechanism involved. The activation energies of 5-hydroxymethyl-2-furfural (HMF) accumulation, sugar -amine interaction and pigment formation have been determined in various model systems and in actual foods. The values obtained are quite similar and usually fall within the range of 24-26kc1/mol (Ameur, Trystram & Birlouez-Aragon, 2006). The values of non-enzymatic browning in the range of ambient storage at abnormal high temperatures are not favourable. It is often observed that foods that are being exposed to higher temperatures in the course of processing darken more rapidly during subsequent storage (Shibukawa, Sugiyama & Yano, 1989; Van-Boekel, 2008).

b. **Effect of pH**: The effect of pH on the rate of browning is more complex because it involves the reaction when the only un-protonated amine combine with sugars such that the rate – determining step of sugar-amine condensation is favored by high pH. On the other hand, the subsequent step of rearrangement is acid catalyzed. Not only does the pH affect the rate of browning, it also determines the predominant mechanism of process, as observed in ascorbic acid browning. In some systems, faster browning is observed both at very low and very high pH regions with minimum at some intermediate pH value (Mundt & Wedzicha, 2007). The effect of pH on the rate of browning is complicated because the pH of the system often changes as the browning reactions take place. The mechanism leading to brown pigments in buffered and non-buffered system may be different (Chopra & Paneser, 2013).

c. **Effect of moisture content**: Within a wide range of water content, the rate of browning increases with increasing solute concentration. Thus, fruit juice concentrate darken faster than single strength juices. However, below a certain moisture level, the rate of browning decreases with decreasing water content (Mundt & Wedzicha, 2007; Wagner, Lucas,Le-Ray & Trystram,2007).
All chemical reactions occur faster as the concentration of the reactants is increased. However, the effect of moisture content on browning cannot be explained quantitatively by this "dilution effects" alone. The mechanism of browning depression at very low moisture is connected with the immobilization of the reactant. It was shown that a suitable non-aqueous solvent when present in sufficient quantity, the maximum is suppressed and the increase in browning rate with decreasing water content becomes continuous, this finding also refutes the validity of the "dilution effect" (Fennema, 1996). In very concentrated systems, browning depressing effect of water is in browning of the browning reaction (dehydration of sugar intermediates) (Fennema, 1996).

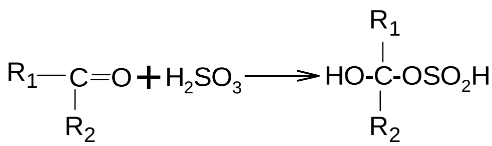
d. **Effect of oxygen**: In the browning that involves ascorbic acid, oxygen is directly involved in the reaction and its effect on browning is predictable. However, oxygen is not essential for the Maillard reaction. In actual food systems, the presence of oxygen has been found to accelerate browning in some cases and inhibit browning in others. In some foods, the effect of oxygen depends on the moisture content and temperature. This is usually interpreted as a proof of the assumption that temperature and moisture not only affects the rate of browning, but may actually change the dominant mechanism of the reaction (Frank, 1983). In contrast to enzymatic browning, exclusion of oxygen or use of antioxidants may not affect the practical prevention of non-enzymatic browning reactions except that of ascorbic acid (Frank, 1983).

e. **Effect of metals:** Browning accelerators and inhibitors, phosphates, carboxylic acids and their salts accelerate non-enzymatic browning and increase the final color intensity. However the effect of metals is not uniform. Copper may be expected to enhance ascorbic acid browning with effect of the oxidation of this substance (Chopra & Paneser, 2013). But for the Maillard reaction, contradicting observations have been reported on the effect of copper and iron. Tin seems to retard non-enzymatic browning in foods. For instance, citrus products packed in lacquered cans go brown much more readily than those packed in plain tinplate containers. The inhibiting effect of tin, at the low pH of these products, may be due to the strongly reducing condition prevailing in such containers (hydrogen, stanneous ions), because the dominant mechanism of browning in citrus products involves ascorbic acid oxidation (Chopra & Paneser, 2013).

Suggestions/ Precautions for Optimum Browning of Some Foods

The best known inhibitor of browning reaction is buffer dioxide. Sulfurous acid and its salts have been long used as browning inhibitors in dried fruits, vegetables and concentrated fruit juices by the following chemical reaction (Bark, 1980; Frank, 1983; Fennema, 1996; Chopra & Paneser, 2013).

1. **Blocking of carbonyl groups**. Sulfurous acid blocks carbonyl groups through a well known addition reaction. -



It has been postulated that sulfur dioxide prevents aldose-amine interaction by blocking the carbonyl groups of the reducing sugar (Fennema, 1996).

2. **Antioxidant effect**. In systems involving ascorbic acid oxidation, sulfur dioxide may be expected to act as an antioxidant, and thus retard pigment formation (Frank, 1983).

3. **Bleaching effect**. The sulfur dioxide might bleach the brown pigments and thus reduce the color intensity. However, the incorporation of sulfur dioxide into systems which are already at an advanced stage of the Maillard reaction does not prevent browning (Bark, 1980).

4. **Practical prevention of browning:** In complex system as foods, it is very difficult to suggest general methods for the prevention of non-enzymatic browning however, these suggestions may be helpful in decreasing the rate of browning to make these foods retain their economic values.

a. Lowering or reducing the temperature: The most helpful method is to refrigerate the foods subject to this type of change. Lowering of temperature generally slows down chemical reaction, especially non-enzymatic browning (Fennema, 1996).

b. Lowering the pH of the product may be of use if the main cause of browning is the melanoldin condensation. (Dried egg powder, for instance, was once made after the addition of the powder with some Na_2HCO_3; the excess acid will then combine with the bicarbonate of soda to form NaCl (Chopra & Paneser, 2013).

c. Lowering the concentration of the final product sometimes decreases the rate of browning. (Grapefruit and lemon juice are often concentrated at a ratio of only 4.1 instead of 6.1, which is usual for orange juice) (Frank, 1983).

d. Maillard reaction requires a free carbonyl group in the sugars, it is sometimes possible to prevent browning of certain food productions by using sucrose instead of reducing sugars, provided, the sucrose will not undergo inversion in the final product during storage. Fructose, as previously mentioned, does not go into combination with amino acids easily and may probably also be used with the same effect. When the sugar constitutes only a negligible part of the product use, as in the case with eggs or meat, it can be removed by fermentation. Eggs are sometimes subjected to fermentation before drying them into powder. Similarly it has been suggested that meat may be fermented before dehydration; ground meat with 5% yeast claimed to be well preserved after dehydration (Fennema, 1996).

e. Another successful method of removing small quantities of sugar is the use of a mixture of two enzymes, glucose oxidase and catalase (commercially available under the name of Dee O). The oxidase converts glucose into gluconic acid (which does not combine with the amino groups) and hydrogen peroxide, while the latter is converted into water and oxygen by catalase (Chopra & Paneser, 2013).

$$R.CHO + O_2 + H_2O \xrightarrow[\text{oxidase}]{\text{glucose}} R{+}COOH + H_2O_2$$

$$2H_2O_2 \xrightarrow{\text{Catalase}} 2H_2O + O_2$$

Conclusion

Food browning is a method of adding value, flavour, colour, aroma and taste. In some foods however, browning is undesirable, such as vegetables, fruits and some tubers, while others require minimum browning to make them attractive. This paper concludes that in most browning the non-enzymatic browning (Maillard reaction) is more acceptable and can be controlled or conditioned with adequate precautions, while the enzymatic browning depends more on the chemical constituents of the materials and thus more difficult to be controlled. The paper advises food processors to adhere to the methods suitable to the different varieties of food to maintain the economic values of the food products.

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