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Review Article

Maillard reaction: formation, advantage, disadvantage and control. A review

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Abstract

The Maillard reaction (MR) is often known as the amino-carbonyl reaction, nonenzymatic browning, or protein glycation reaction. The non-enzymatic browning reaction is influenced by several factors like period, quantity of H₂O, temperature, involved reactants, pH, and metal ions in food. During the production, processing, and storage of food, the MR is a crucial chemical process. While Maillard reaction products (MRPs) can enhance food quality during processing, some unfavorable reactions can also result in undesirable food effects. There are two sides to MRPs. The positive side is that these products have several advantages such as improvement in color, odor, flavor, and antioxidant ability. On the other hand, the negative side represents decreasing food quality and the nutritional value of some foods, as well as some health-related problems. The review involves several strategies by which MR could be controlled or prevented. These strategies were divided into two parts, the first is non-enzymatic which is done by adding functional ingredients that work to modify reducing sugars and amino groups and/or trapping of α -dicarbonyl compounds. The second is enzymatic, by using enzymes for example, fructosamine kinase, fructosamine oxidase, and lactose oxidase.

Keywords

Maillard reaction, food quality, food processing, Maillard reaction control

Abbreviations

AA – amino acids; ABV – alcohol by volume; AGEs – advanced glycation end products; APIs – active pharmaceutical ingredients; FAD – flavin adenine dinucleotide; FADH – flavin adenine dinucleotide (reduced form); Faox – fructosamine oxidase; HMF – hydroxymethyl furfural; MR – Maillard reaction; MRPs – Maillard reaction's products; ROS – reactive oxygen species; RS – reducing sugar;

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Introduction

The Maillard reaction (MR) is a non-enzymatic browning reaction, that comprises a condensation between a carbonyl group (ketone or aldehyde) in a reducing sugar (RS) and an amino group in amino acids (AA), peptides, and proteins in the presence of heat (Hodge 1953; Törös et al. 2023). It is among the most significant and intricate processes associated with food chemistry since numerous constituents can interact through various paths to create a complex mixture of products (Moreno et al. 2003).

MR commonly occurs during the manufacturing and storage processes. It produces a large number of

compounds (Fig. 1), including furan, HMF (hydroxyl methyl furfural), advanced glycation end products, and brown pigments known as melanoidins beside volatile compounds mainly acrylamide, heterocyclic compounds and polycyclic aromatic hydrocarbons (Kathuria et al. 2023; Viegas et al. 2012). These compounds may have a positive effect sometimes and a negative effect, which may lead to desirable changes in flavors and colors in many foods such as bakery products, meat, coffee, and toast or it may lead to undesirable changes in flavors and colors in other foods, like fruit, vegetables, milk and eggs (Hafsa et al. 2021; Lee et al. 2017; Yu et al. 2018).

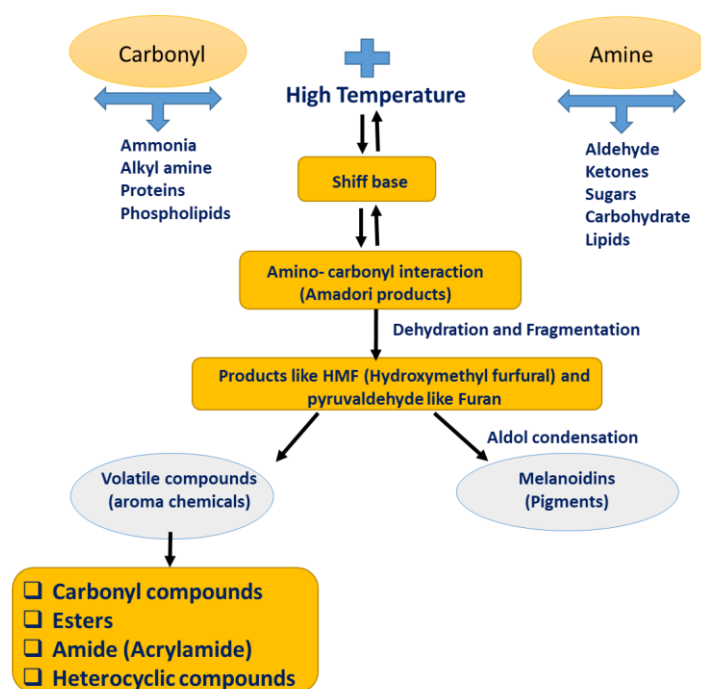


Figure 1. A simplified schematic illustrating how the Maillard reaction product is formed during the processing of food

The MR in foods can be affected by many chemical factors alike the amount of initial substances, acidic medium (pH = 4-7), and water content (Ajandouz et al. 2001). In addition, the RS nature of ketose (fructose) is less reactive than aldose (glucose and galactose) (Yeboah et al. 1999). Physically, the reaction rate is positively affected by factors such as process and storage temperature, O₂, storage time, packaging, and increased heating, which accelerates the formation of brown color in cooked foods (Naranjo et al. 1998; Schmutzler et al. 2021). The

MR in food has been evaluated using both chemical and biological methods. The buildup of brown pigments is the most visible sign that the MR has taken place in foods containing both protein and carbohydrates. Visual observation and subsequent rating, coefficient of reflection methods, quantitative analytical methods, and spectrophotometric approaches have all been used to track pigment buildup or browning (Choi et al. 1949). The controlling of MR is important not only because of its role in aroma, flavor, and color but

also because of the potential toxicity of the reaction products. These reactions can be controlled by creating unsuitable reaction conditions or by adding some chemicals that stop the reaction through a certain mechanism (Wu et al. 2023).

Mechanism of Maillard Reaction Formation

MR is started when amino groups in protein, peptide, and AA combine with carbonyl groups in RS (Figure 2). This results in the creation of Schiff bases, which then undergo rearrangement to form Heyns or Amadori products (Hellwig et al. 2014; De Oliveira et al. 2016). These compounds are broken down to produce reactive dicarbonyl types, which readily react with other nucleophiles like amines,

thiols, and guanidines. Strecker degradation might occur when these intermediates condense with free AA, creating imines, which after that fragment to form Strecker aldehydes, that are essential for flavor advancement in foods like coffee, cocoa, bread, dark beer, and roasted meat (Zhang et al. 2020). However, they are perceived as off-flavors in other foods like ultrahigh-temperature processed milk and pilsner beers (Jansson et al. 2014; Jansson et al. 2014). The advanced stage involves the polymerization of low molecular mass intermediary substances and generates a higher molecular mass colored polymers, melanoidins. These reactions consist of isomerization, post-acetal reaction, cyclization, dehydration, rearrangement, and others (Hodge 1953).

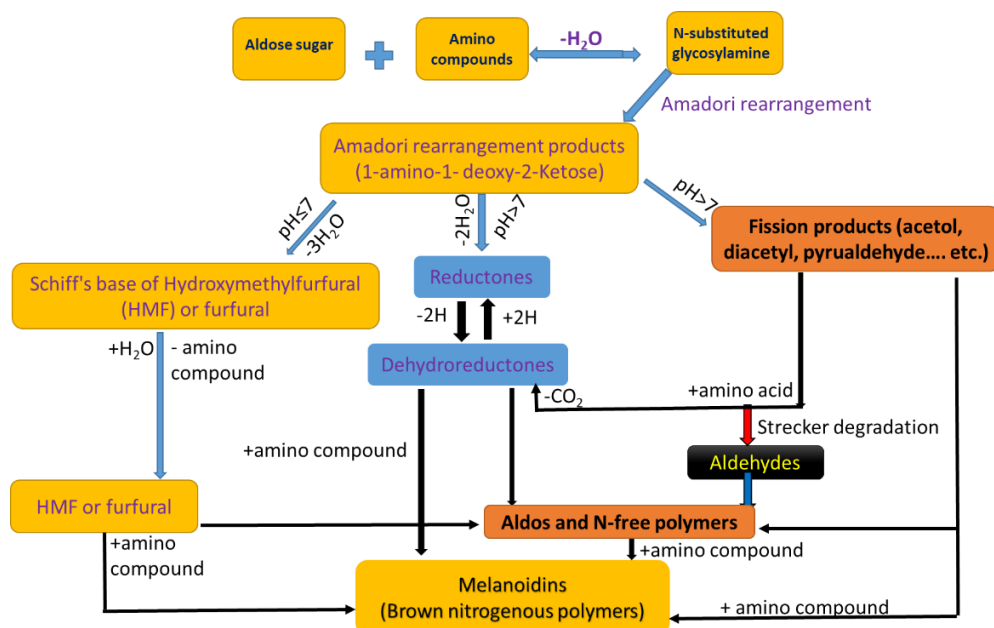


Figure 2. The Maillard reaction process.

Adapted by Fu et al. (2019) with modification. Copyright 2019, John Wiley and Sons

Effects of Maillard Reaction on the Quality of Food Products

MR has an impact on the organoleptic characteristics, color, and protein content of food. Ames (1990) claims that specific temperature and time profiles utilized during food processing are applied to create aroma profiles that are unique to each food. While MR can help create delicate flavors and other desired changes, they can also lead to unfavorable quality changes, especially if they are overly pronounced and produce bitter or burnt

flavors. Controlling MR for the duration of food manufacture and storage is crucial for maintaining food superiority. The MR and the caramelization of sugars cause color to develop during baking. Apart from having a significant impact on consumer acceptance of products at first, this phenomenon is also responsible for other significant changes in food during baking, such as the production of flavor and aroma compounds, the formation of toxic products (e.g. acrylamide), and a reduction in protein nutritional value (Purlis 2010). Milk protein and lactose are the dual main nutritional

components of milk. These ingredients are used as reactants in the MR, resulting in MRPs, which affect the value of milk and dairy products (Xiang et al. 2021; Cadwallader and Singh 2009). On this basis, MR has advantages, disadvantages, and needs to be controlled to obtain the desired result, (Figure 3) which we review below.

Advantages. Improvement in Color, Odor, and Flavor

The majority of food consumed in developed societies today is processed. The demand for more safe, convenient, and varied food products grew exponentially over the last century, as did the diversity of processed food products. Thermal processing is used to preserve foods by inactivating microbes, improve sensory qualities (flavor, taste, and smell), or extract another food product or

ingredient from a food source, such as cheese and oils (Peng et al. 2017; Alabbas et al. 2022).

The MR occurs in a wide range of foods, from seared steaks and fried fish to biscuits, bread, and toasted marshmallows. The differences in cooking aromas are caused by various food types. Numerous techniques were devised to optimize the MR, which is predictable as a fundamental factor in developing food flavor. Scientists have been focusing on identifying MRPs that could be castoff for flavor enhancement in the food industry because it is the products of the MR reaction that impart the desired flavor (Nooshkam et al. 2019; Cui et al. 2019). Aromas are primarily produced through the reaction of lactose and milk protein in heat-treated dairy foodstuffs for example ultra-heat-treated milk powder and cheese. MRPs such as furfuryl alcohol, hydroxymethylfurfural, furfural, 2-acetyl furan, maltol, and other low molecular mass compounds.

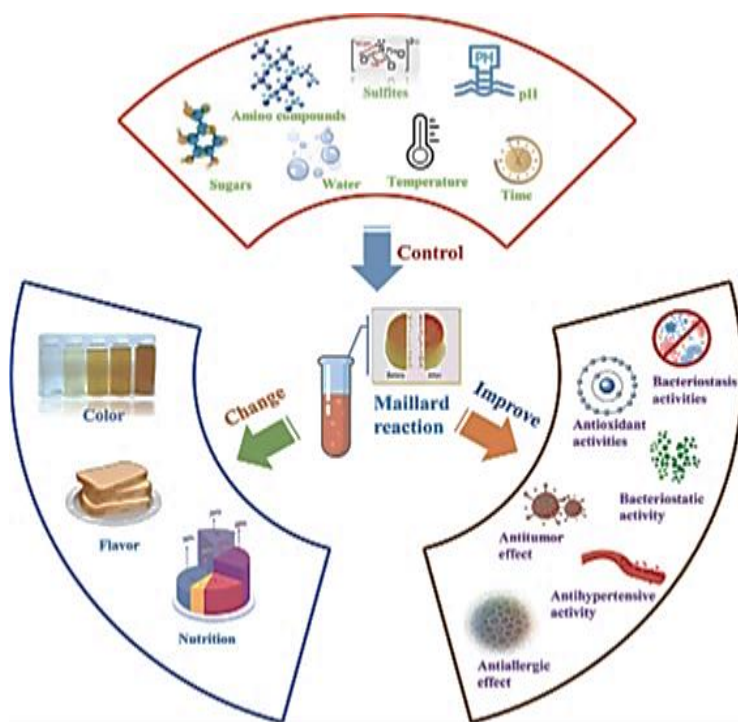


Figure 3. The areas of interest and scientific content for MR and its improvement. Reproduced with permission from Liu et al. (2020). Copyright 2020, John Wiley and Sons

primarily produce these aromas (Newton et al. 2012; Rada-Mendoza et al. 2022). In addition, the MR has the potential to improve food flavor.

The MRPs were able to improve the flavor of Cantonese sausages by reducing the stickiness and

increasing the chewiness of the sausages (Sun et al. 2010).

Table 1 illustrates some modifications that have happened in food during the stages of MRPs generation.

Table 1. Modification of food during the stages of MRPs generation

Modification of food	Initial stage	Intermediate stage	Final stage
Color change or discoloration	-	+	+++
Off-flavor or flavor change	-	+	++
Toxicity development	-	unknown	unknown
CO ₂ production	unknown	+	unknown
Lost of protein's value	+	+	+
Metals chelation value	-	unknown	+
pH value decrease	unknown	unknown	unknown
Increasing value of antioxidant activity	+	+	+
Solubility decrease	-	-	+
Lost of activity of vitamin C	+	-	-
Water production	+	+	+

Antioxidants

The MR has been linked to the formation of compounds, which have strong antioxidant properties (Figure 4). One of the beneficial effects of MR is the formation of antioxidant molecules (Habinshutiet al. 2019; Cao et al. 2022). MRPs function as antioxidants via scavenging active oxygen, chelating metal ions, and eradicating H₂O₂ and free radical chains. The advanced and intermediate-stage reaction byproducts of the MR are primarily responsible for the antioxidant activity (Nooshkam et al. 2019). Because some synthetic antioxidants may have a negative impact on humans, consumers prefer MRPs to substances like tert-butyl hydroquinone, butylated hydroxyanisole, and butylated hydroxytoluene (Shahidi 2000). MRPs with different molecular masses have different antioxidant activities. The metal chelating potential of high molecular mass MRPs is higher than that of low molecular mass MRPs, according to a study by Yoshimura et al. (1997). This could be

due to hydroxyl or pyrrole groups consequent from MRPs. Studies have demonstrated that derivatizing proteins using the MR increases their functional characteristics and value in the food industry (Oliver et al. 2006). Improved hydrogen bond strength, gel firmness, and water-holding capacity were seen in ice-set gels created using MRPs of whey separated proteins and maltodextrins in a 1:1 ratio, as well as a lesser gel swelling. The MR could enhance the lathering properties of milk proteins (Meydani et al. 2019). According to research of Jarunglumlert et al. (2015), milk protein can use the MR to transform into a more stable glycosylated protein that can carry out all of its occupations as a drug transferor. Studies have demonstrated that MRPs can enhance food's antioxidant possessions, exclusively lipid-based foods that are prone to oxidation (Shahidi 2000). Several illnesses are linked to a deficiency of the antioxidant coenzyme Q₁₀, making supplementation necessary. This antioxidant has a low solubility in water. By using MR to form a covalent bond between dextran and casein, stable casein glycosylated micelles could be created as a coenzyme Q₁₀ carrier, significantly enhancing solubility and bioavailability (Muhoza et al. 2017). Other research demonstrates that the conjunction of MRP and curcumin performs better than casein micelles in terms of boosting curcumin stability and neutralizing harmful free radical activity (Wu and Wang 2017). The MRPs could develop the antioxidant properties and thermal stability of anthocyanins, which are sensitive to heat and acid (Qin et al. 2018). The encapsulation rate and suitability for enveloping are all higher in MRPs made from whey proteins with isomalt oligosaccharides fermented at 90 degrees (Liu et al. 2016). Studies have demonstrated that the MR compound melanoidins have anti-oxidant, antiseptic, probiotic, and antitumor activities in the humanoid intestine (Wang et al. 2011).

Disadvantages

The MR has a slew of negative side effects. The most visible of which can be found in food. Many studies currently show that MRPs intake through food is linked to a variety of diseases (Rifai and

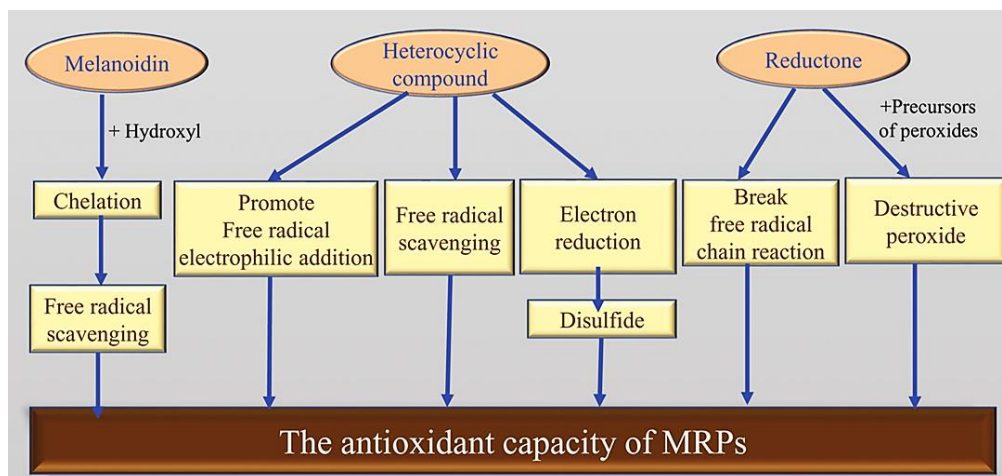


Figure 4. Antioxidation mechanism of Maillard reaction products. Reproduced with permission from Liu et al. (2020). Copyright 2020, John Wiley and Sons

Saleh 2020). Drug bioavailability, active substance degradation, color changes, formation of toxic substances, and drug uptake could be caused by MR (Nooshkam et al. 2020; Liu et al. 2022b). In this review, we will discuss the most important disadvantages associated with our daily lives resulting from these interactions, represented by:

Food Quality Problems

One of the most common causes of food spoilage is the MR. Food with a reasonable MR can have faint flavors, but food with a high MR will have bitter and scorched tastes (Hirsch et al. 1992). The MR between lactose and milk protein is the primary source of dairy product quality problems. When temperature and moisture are not properly controlled during the milk powder production or storage process, MR causes a conversion in color and bad smell of milk powder (Karagül-Yüceer et al. 2001). Odorous MR reaction compounds such as maltol and furaneol primarily cause the off-odor cheese. When the temperature of cheese is heated above 120°C for 5 min, it emits a peculiar odor, which is primarily caused by maltol and furaneol (Bertrand et al. 2011; Bertrand et al. 2015). Protein cross-linking may also occur as a result of MRPs with proteins. Dairy products' protein cross-linking is caused by the production of MRPs or dehydroalanine, resulting in discoloration and a variety of problems, including poor solubility, foaming, and emulsification (Le et al. 2011; Al-

Saadi et al. 2013). Storage and processing of spray-dried whey protein isolate and ascorbic acid undergo MR, resulting in a red ingredient of formyl threosyl pyrrole, which degrades the product value (Zhong et al. 2019).

Diminish the Nutrient Value of Foods

During processing and storage, the MR is known to cause serious food quality degradation. The availability of AA and proteins is significantly reduced by these compounds formed under mild conditions, according to growing evidence. The nutritional value of foods that undergo the MR is found to be significantly reduced, even after accounting for the loss of biologically available lysine. *In vivo* and *in vitro* methods were used to assess the nutritional quality of egg albumin as a function of the extent of Maillard browning with storage periods of less than ten days (Tanaka et al. 1977). The main factors affecting the damage extent are the MR progression, storage duration, and temperature (Ford et al. 1983). MRPs will also influence the levels of trace elements by lowering iron, phosphorus, and magnesium bioavailability (García et al. 2009; Delgado-Andrade et al. 2007; Delgado-Andrade et al. 2011).

During the preparation and storage of food, the MR could produce harmful compounds like acrylamide, carboxymethyl lysine, and heterocyclic amines (Al-Jahdali and Carbonero 2019; Tagliamonte et al. 2023). MR, which produces malt flavor and color

compounds, is responsible for the flavor and color complexes produced for the period of thermal dealing of specialty malts. Depending on their nature and quantity, these chemical compounds can provide a beer with varying vibrant colors and flavors, affecting the particular qualities of the finished beer product (Liscomb et al. 2015; Carvalho et al. 2016). The higher presence of these products in beer brewed with malts could be also interconnected to the decrease in alcohol by volume (ABV) in those beers. Specific MRPs have been shown to inhibit yeast metabolism in previous research (Coghe et al. 2005; Taherzadeh et al. 1999). Brewers are interested in the effect of specialty malts on ABV because it is an important quality pointer in beer. After all, it designates the strong point of the beer and influences, mouthfeel, and flavor (Castro et al. 2021).

Human Health

Some of the chemicals produced by MR are known to be potentially harmful (mutagens, carcinogens), antinutritional, or simply undesirable. The effect of MR on human health is hotly debated. It modifies lysine, an essential AA, and is bound to reduce the nutritious value of foodstuffs. (Perez-Locas and Yaylayan 2010; Cha et al. 2019; Murata et al. 2021). According to *in vitro* and *in vivo* studies, proteins modified by MR may hurt protein digestibility (Seiquer et al. 2006; Gilani et al. 2012). This might be explained by altering the enzymatic sites at which intestinal proteases cleave proteins, which would decrease proteolysis (Joubran et al. 2015; Chevalier et al. 2001).

Recent evidence indicates that MRPs, particularly advanced glycation end products (AGEs), have a proclivity to generate reactive oxygen species (ROS), and partial MRPs have been linked to diseases for example aging, chronic diabetes mellitus (Manch et al. 2002; Baynes, 2002) Parkinson's (Stitt, 2001; Zhang et al. 2020) and Alzheimer's disease (Wu et al. 2011).

Endogenous AGE formation is also connected with innumerable inflammatory circumstances and might donate to the progression of renal failure (Uribarri et al. 2010), chronic heart failure (Hartog et al. 2007), and atherosclerosis (Wang et al. 2011). These chemicals have serious health repercussions

due to their neurotoxicity, genetic toxicity, carcinogenicity, liver toxicity, reproductive toxicity, and immunotoxicity. Rifai and Saleh (2020). It has been demonstrated that AGE creation on protein allergens increases T-cell immunogenicity, and this is thought to contribute to the pathogenesis of food allergies (Ilchmann et al. 2010). Two pathways primarily characterize AGEs in human bodies: *in vitro* intake and *in vivo* transformation, with food and herbal medicines being the primary sources of AGE formation (Wu et al. 2011). These diseases are primarily caused by proteins that attach to receptors on the surface of cells or crosslink with additional proteins *in vivo*, exchanging how they function, and structure, inducing a state of oxidative stress and inflammatory conditions (Xu et al. 2021).

Drug

The vast majority of drugs function as amines. When these medications are combined with RS or other medication additives that contain carbonyl, the resulting dosage form frequently develops extensive mottling or discoloration over time (Panel et al. 2005). The pharmacological usages of MR are still relatively partial, although several new investigations have described an improvement of nanoparticulate drug transfer systems established on the self-assembly of polysaccharide-protein Maillard conjugates (Edelman et al. 2017; Wang et al. 2017).

In the therapeutic industry, MR reasons issues in pharmaceutical preparations, compromising drug security and efficacy. The MR, on the other hand, may have some beneficial impacts on pharmaceutical preparations (Marko et al. 2003). The MR between the excipient lactose and drugs that contain amino groups always has stayed a barrier to lactose and its pharmaceutical formulations being widely used. When making generic drugs, many pharmaceutical manufacturers substitute an excipient for lactose in their original formulation that does not interact with the API. This will have an impact on the drug efficacy and make drug consistency testing more difficult. In addition to coloring the formulations, the MR between the lactose and APIs will additionally lead to an active substance degradation, producing harmful substances (Lovdahl et al. 2002). Aminophylline, a

primary amine medication, will react with lactose through MR and form a brown color after three weeks (Hartauer and Guillory 1991). According to Abdoh et al. (2004) the MR between lactose and APIs is the primary reason for amlodipine besylate degradation. In animal experiments, it was discovered that the MR between lactose and nebivolol causes nebivolol to lose its pharmacological activity (Patil and Patil 2013). The primary amine in pregabalin affects the central nervous system. In the initial formulation, lactose made up one of the excipients. Pregabalin-like pharmacological activities have been found in the MRP of pregabalin and lactose in recent studies (Marko et al. 2003).

Maillard Reaction Controlling

Many strategies for regulating MR have already been researched over time. Figure 1 depicts some examples of reactants or intermediaries that have undergone alteration to regulate MR, including RS, AA, Amadori product, Strecker aldehyde, and dicarbonyl group. To create efficient MR control strategies, one must have a thorough understanding of the mechanisms of reaction as well as how triggers impact MR. In this review, we will explain some of the enzymatic and non-enzymatic strategies used to control these reactions.

Non-enzymatic strategies

Trapping of α -dicarbonyl. Several more efforts have been made to identify MR inhibitors in foods and *in vivo*. Although recently the focus has shifted to trapping α -dicarbonyl molecules, certain compounds have been suggested to prevent MR through radical scavenging, interaction with Amadori products, and trapping of particular MRPs like Strecker aldehydes and acrylamide (Hirsch et al. 1992; Chen et al. 1993). Aminoguanidine, which works by trapping α -dicarbonyls, was unique of the first pharmacological drugs revealed to be accomplished for inhibiting MRPs (Delgado-Andrade et al. 2007). Polyphenols from various plant sources have gained increasing attention as Maillard inhibitors in nutrition systems since they are considered natural compounds and thus more accepted as food ingredients than unnaturally manufactured compounds. In plants like grapes, cocoa, and tea, a polyphenol called epicatechin

binds to α -dicarbonyls. Vitamins, AA peptide derivatives, and other naturally occurring compounds have been also found to inhibit MR by directing reactive sites, intermediates, or producers (Colahan-Sederstrom and Peterson 2005).

The removal of any reactants (AA or RS) or the addition of compounds that contain sulfur, for instance, SO_2 or N-acetylcysteine, that obstruct the reactions or result in colorless reaction products, have historically been the primary methods used to interfere with MR by either synthetic or natural compounds (Friedman 1996). Glyoxal, methylglyoxal, and deoxyosones, which are reactive intermediates that speed up MR because of their greater reactivity than glucose, are formed when Amadori or Heyns products are fragmented and dehydrated. It has been demonstrated that many medications and food components that stifle MR also trap α -dicarbonyls. As a result, it is believed that at least one of the key pathways these compounds prevent the buildup of MRPs is through α -dicarbonyl trapping (Mittelmaier and Pischetsrieder 2011; Cha et al. 2019). Phenolic acids and phenols exist in numerous classes of plant food and have also been shown to exhibit α -dicarbonyl trapping. A-ring is an active position for flavonoids, helping to their capacity to scavenge α -dicarbonyl, according to all reported studies (Shao et al. 2014; Khan et al. 2020). Wu and co-authors indicated that many different polyphenol compounds, primarily flavonoids, and phenylpropanoids occurred in cinnamon, tea, mate, rosemary, and additional herbal plants, and have been demonstrated to be efficient α -dicarbonyl trapping agents (Wu et al. 2011). Flavonoids and phenylpropanoids have highly activating hydroxyl groups on the A-ring that make para- and ortho-directed electrophilic aromatic substitution possible. It is primarily through the use of this mechanism that α -dicarbonyl species are trapped (Brown et al. 2005). Chlorogenic acid-derived substances and amine-quinone adducts, both of which may color foods, are a dark-colored green species and a red species, respectively, in the sunflower meal-based cookies. Additionally, additives between unoxidized (+) catechin and glyoxylic acid, an oxidation byproduct of tartaric acid found in wine, have been demonstrated to influence color changes (Es-Safi et al. 2000).

On the other hand, thiol compounds like homocysteine, cysteine as well and glutathione have been reported as trapping agents (Zeng and Davies 2006). These additives are used in wine to stop browning brought on by polyphenol polymerization, which results in the establishment

of colorless adducts of thiol-quinone (Pierpoint 1969; Singleton et al. 1985). Thiol compounds have been also started to trap α -dicarbonyls nevertheless due to the possibility of off-flavor formation, this method would require to be prudently controlled in foods in terms of thiol source and concentration. For instance, thiols supplementary to beer are being shown to improve "sewerlike" off-flavors (Zeng and Davies, 2006; Gijs et al. 2004).

Reducing Sugar Modification

Reactivates of various RS vary; pentose sugars such as ribose are more combative than glucose and lactose. (Chevalier et al. 2001; Ledesma-Osuna et al. 2008). Galactose is furthermore more active than glucose because it contains a more open-chain form in a steady state compared to glucose in solution. It has been demonstrated that starter cultures can stop the cheese from browning by fermenting RS into nonreducing sugars (Chevalier et al. 2001; Mukherjee and Hutkins 1994).

Modification of Amino Group

It has been proven that protecting lysine since additional adaptation during storing at 50°C involves modifying amines on lysine in whey proteins separate by succinylation and acetylation. MR inhibition has been successfully achieved by modifying amines (Lakkis and Villota 1992). More recently, it has been suggested that modifying amines with oxidized polyphenols, like quinone, could prevent or modify MR (Guerra and Yaylayan 2014; Troise et al. 2014). Quinones are easily created during processing and storage in foods containing polyphenols (Jongberg et al. 2011), and they undergo a Michael addition to produce either amine-quinone adducts or benzoquinone imines (Pierpoint 1969; Li et al. 2016).

Enzymatic Strategies

Enzymes are frequently employed in the treatment of food and ingredients for the reason that they

suggest a "clean label" option, making them a preferred method for food producers. Enzymes are typically rendered inactive during the last stages of processing (pasteurization), so their inclusion on the list of components is not required. To delay the onset of MR in foods, numerous enzymes have been used. The usage of enzymatic interference against this event will be illustrated in the following:

Fructosamine Oxidase (Faox)

Oxidoreductases contribute to catalyzing the conversion of RS to corresponding lactones, which when present in water-based conditions break down into acids (Bankar et al. 2009). Even though this mechanism has been proposed as a useful technique and does reduce the abundance of RS to prevent some food products from browning (Lin and Zheng 2010). Faox, an enzyme that facilitates the process of oxidative deglycation of Amadori products and can be utilized for protein repair, is receiving attention as a potential means of lowering MR in foods (Troise et al. 2014).

On the other hand, the alike levels of Lys found in milk that has undergone Faox treatment and milk that has not may be brought about by additional Lys modifications that are introduced concurrently with the deglycation. Therefore, it is advised that more research be done Faox is considered for use in food demands to determine the effects of this reaction pathway on food quality (Henning et al. 2011).

Fructosamine Kinase

In the Amadori product, the fructosamine kinase phosphorylates the hydroxyl group that is found after the carbonyl. The 3-deoxyglucosone moiety, phosphate, and amino moiety of the protein are then restored by deglycating this phosphorylated intermediate. Although this technique decreased the accumulation of Amadori products in bacteria, it is still unclear whether it can be used in food classifications. Particularly in the existence of 3-Deoxyglucosone, additional protein modification or HMF accumulation may occur (Deppe et al. 2011).

Lactose oxidase

When the redox cofactor FAD is present, lactose oxidase can oxidize lactose to lactobionic acid while also reducing FAD to FADH. Then oxygen is

reduced to H_2O_2 and FADH oxidizes to FAD. H_2O_2 will oxidize free thiols to disulfides in the attendance of metal ions or lactoperoxidase system, which still has some activity in the pasteurization of milk. This process reduces the flavor that comes from free thiols. Unwanted oxidative protein and lipid adjustments may happen unless the release of H_2O_2 must be tightly controlled, such as by using catalase, even though this might reduce a single source of off-flavor. MR is also not anticipated to be influenced (Barrett et al. 1999; Goulding et al. 2020).

Conclusions

Maillard reaction can be accomplished through the covalent linkage between constituents bearing carbonyl and free amino groups. These reactions consequences in a widespread diversity of compounds, named MRPs. The MR is crucial to the production of food, herbal remedies, pharmaceuticals, and even human life. It typically happens in the processing and storage of foods and herbal medicines. In addition to producing a large number of effective components. We conclude in this review that these compounds are of great importance and usefulness related to improving the color and flavor of food and their antioxidant capacity in numerous food products, via chelation of metal ions, hydrolysis of H_2O_2 , scavenging of reactive oxygen species and radical chains, but at the same time, they have multiple harmful effects, such as their effect on food quality and reducing the nutritional value of food. In the past limited years, other health harms that can be caused by these compounds generated in food are related to the development of various diseases.

It is clear from the research discussed here that there most likely isn't a single "magic bullet" that will entirely inhibit or enable control of these pathways. We have outlined several strategies that can prevent or control MR. These strategies may be non-enzymatic by trapping of α -dicarbonyl, RS modification, and modification of amino group, or enzymatic using some safe enzymes such as fructosamine oxidase, fructosamine kinase, and lactose oxidase.

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