ANALYZING THE ROLE OF CHEMICAL REACTIONS AND TRANSFORMATION IN FOOD PROCESSING AND THEIR EFFECT ON NUTRITION VALUE.

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Abstract

Food processing plays a crucial role in meeting the demands of modern society, providing convenience, safety, and extended shelf life to a wide variety of food products. However, the chemical reactions and transformations that occur during food processing can have significant effects on the nutritional value of the final products. This mini review paper aims to analyze the role of chemical reactions and transformations in food processing and their impact on nutrition value. The paper discusses three key types of reactions: the Maillard reaction, oxidation reactions, and enzymatic reactions. It explores how these reactions influence flavor, color, texture, and shelf life of processed foods, and examines their effects on the nutritional value, such as the formation of advanced glycation end products (AGEs), degradation of vitamins and antioxidants, and enzyme-mediated nutrient degradation or activation. The paper also highlights the loss of vitamins and minerals during food processing, the formation of potentially harmful compounds, and the nutritional changes that occur in processed foods. Strategies to minimize nutrient loss and harmful compound formation, as well as techniques to enhance or preserve nutritional value in processed foods, are also discussed. Understanding and optimizing food processing techniques is essential for maximizing the nutritional benefits of processed foods and ensuring a healthier diet for consumers.

Keywords: Chemical reactions, Food processing, Nutrition value, Maillard reaction, Nutrient degradation

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1. Introduction

Food processing plays a crucial role in modern society, as it enables the transformation of raw agricultural products into edible and convenient food products. This process involves a myriad of chemical reactions and transformations, which are essential for enhancing food safety, extending shelf life, and improving nutritional quality. The complexity of these chemical reactions poses significant challenges for food scientists and engineers, as they must identify, characterize, and model the most significant reactions occurring under various processing conditions (Segovia-Bravo et al., 2011; Ramírez et al., 2009). Factors such as pH, temperature, and exposure time during processing can favor specific transformations in food, highlighting the importance of understanding the underlying chemistry (Friedman, 1999). Additionally, the use of natural antioxidants in food processing has gained prominence, reflecting the shift towards natural products over synthetic ones in the food industry (Kumar et al., 2015).

One of the critical reactions in food processing is the Maillard reaction, which contributes to the flavor, aroma, and color of processed foods. Controlling this reaction is essential to prevent the formation of undesirable compounds such as acrylamide, thereby ensuring food safety and quality (Jaeger et al., 2010). Furthermore, the physical and chemical alterations to proteins during food processing have implications for nutrition, emphasizing the need to consider the impact of processing on the nutritional properties of food (Gerrard et al., 2012). However, it is important to note that modern thermal cooking or processing can also lead to the formation of toxic compounds, highlighting the potential risks associated with chemical reactions in food processing (Mmehime et al., 2018).

The significance of food processing extends beyond chemical transformations, encompassing aspects of food safety, consumer perception, and sustainability. The use of food additives in processed foods has become indispensable to meet consumer demands for value and convenience, emphasizing the integral role of food processing in meeting societal needs (Shim et al., 2011). Moreover, developments in food processing technologies have transformed the modern diet by removing abrasive and fibrous content, reflecting the impact of processing on dietary patterns in industrialized societies (Silvester et al., 2021).

In conclusion, food processing is of paramount importance in modern society, driving the availability of a diverse range of food products while addressing food safety, nutritional, and sustainability considerations. Understanding the chemical reactions and transformations occurring during food processing is essential for ensuring the safety, quality, and nutritional value of processed foods.

2. Chemical Reactions and Transformations in Food Processing

Food processing involves a multitude of chemical reactions and transformations that are crucial for the development of various food products. The Maillard reaction, which occurs between amino and carbonyl compounds, is particularly important in food processing, contributing to the flavor, aroma, and color of processed foods Brands & Boekel (2001)Zhou et al., 2020; Ismarti et al., 2020). Additionally, oxidation reactions play a significant role in the deterioration of proteins in food, comparable in importance to reactions such as the Maillard reaction (Hellwig, 2019; Domínguez et al., 2021). These reactions can lead to the formation of Maillard reaction products, which have been found to exhibit protective effects against oxidative stress (Pyo et al., 2016).

Furthermore, the Maillard reaction has been optimized using response surface methodology to improve the appearance, taste, and functional properties of food (Ismarti et al., 2020). Model food systems with Maillard reaction products have been utilized to assess process lethality for thermal pasteurization applications (Bornhorst et al., 2017). The Maillard reaction, along with lipid oxidation, is considered one of the most important chemical reactions occurring in foods during processing and storage (Zamora & Hidalgo, 2011). Moreover, the formation of aminoreductone during the Maillard reaction is crucial for creating desirable and unique flavors in food products (Trang, 2018).

In addition to the Maillard reaction, the study of protein oxidation in muscle foods has been recognized as essential, given its ubiquitous occurrence in fresh and processed meat and fish products (Domínguez et al., 2021). Furthermore, the application of natural antioxidants from vegetable peels has been explored to mitigate oxidation reactions that produce free radicals, which can damage cells (Sonia et al., 2016). The functionality of Maillard reaction products derived from milk protein has been enhanced through lactic acid bacteria fermentation, demonstrating the potential for improving food properties through controlled reactions (Oh et al., 2015). Novel approaches to the analysis of the Maillard reaction of proteins have been developed, emphasizing the importance of understanding and characterizing these complex reactions in food science and medicine (Fayle et al., 2001).

2.1 Maillard reaction

The Maillard reaction, also known as non-enzymatic browning, is a complex chemical reaction between amino compounds and reducing sugars that occurs during food processing and storage. This reaction is essential for improving the appearance, taste, and functional properties of food products Ismarti et al. (2020). The Maillard reaction contributes to the development of delicate flavors and desirable changes in food, while excessive reaction can lead to the formation of bitter and burnt flavors (Lund & Ray, 2017). It is a common reaction between amino compounds and carbonyl compounds, generating various volatile flavor compounds such as aldehydes, ketones, pyrazines, and furans, which give foods an attractive and pleasant aroma (Xu et al., 2019; Zhou et al., 2016). The reaction also produces a diversity of sensory-active compounds, including those that contribute to aroma, taste, and color characteristics found in foods (Cerny, 2008).

The Maillard reaction significantly impacts the flavor, color, and aroma of processed foods. It is responsible for the generation of delicate flavors and the development of attractive aromas in various food products (Xu et al., 2019). Additionally, the reaction is known to impart taste attributes and generate aroma and taste-active compounds, contributing to the overall flavor profile of foods (Jiang & Peterson, 2009). Furthermore, the Maillard reaction is a series of complex reactions that generate volatile small molecules and brown macromolecules, significantly influencing food color and aroma (Zhou et al., 2016).

In terms of nutritional value, the Maillard reaction has implications for the formation of advanced glycation end products (AGEs). These compounds are formed during the Maillard reaction and have been proven to be detrimental to human health (Zhang et al., 2023). The reaction involves the binding of the carbonyl group of reducing sugars to the amino group of amino acids, leading to the formation of AGEs, which are associated with various diseases, including diabetes and atherosclerosis (Nagai et al., 2002). Additionally, the Maillard reaction can contribute to the formation of covalently cross-linked composites in proteins, such as human serum albumin, which undergoes glycation to form AGEs (Iqbal et al., 2016).

In conclusion, the Maillard reaction plays a pivotal role in food processing, influencing the sensory attributes of foods, including flavor, color, and aroma. However, it is essential to consider its potential impact on the formation of AGEs and its implications for nutritional value and human health.

2.2 Oxidation reactions

Oxidation reactions play a significant role in food processing, impacting food quality and nutritional value. These reactions are among the deterioration reactions of proteins in food, comparable in importance to other reactions such as the Maillard reaction and lipid oxidation Hellwig (2019). The in-depth scientific knowledge on the formation, reactions, quenching mechanisms, and kinetics of singlet oxygen can greatly improve the quality of foods by minimizing oxidation during processing and storage (Min & Boff, 2002). Oxidation occurs ubiquitously in muscle foods, such as fresh and processed meat and fish products, leading to the spread of off-flavors and undesirable tastes, resulting in a shorter shelf life (Domínguez et al., 2021). Furthermore, oxidation reactions can produce free radicals, which start chain reactions that damage cells, impacting the nutritional value of food products (Sonia et al., 2016).

The impact of oxidation reactions on food quality is substantial, as they lead to the spread of off-flavors and undesirable tastes, affecting the sensory attributes and shelf life of food products (Domínguez et al., 2021). Lipid oxidation, in particular, can result in the development of rancid flavors and odors, negatively impacting the overall quality of food products (Khormizi et al., 2019). Additionally, oxidation reactions can lead to the generation of volatile compounds that contribute to the aroma and taste of foods, influencing consumer perception and acceptability (Peterson & Totlani, 2005). The spread of off-flavors and undesirable tastes due to oxidation reactions can result in a decrease in the nutritional quality of food purchases, affecting consumer behavior and food choices (Spiteri & Soler, 2017).

In terms of nutritional value, oxidation reactions can have detrimental effects on the quality and safety of food products. The formation of free radicals during oxidation reactions can lead to the degradation of essential nutrients and bioactive compounds, impacting the overall nutritional value of foods (Sonia et al., 2016). Additionally, oxidation reactions can result in the loss of nutritional quality and the development of off-flavors, affecting consumer satisfaction and food acceptability (YUSOFF et al., 2022). Furthermore, the spread of off-flavors and undesirable tastes due to oxidation reactions can lead to a decrease in the nutritional quality of food purchases, impacting consumer behavior and food choices (Spiteri & Soler, 2017).

In conclusion, oxidation reactions significantly impact food quality and nutritional value by affecting sensory attributes, shelf life, and the degradation of essential nutrients and bioactive compounds. Understanding and controlling oxidation reactions are essential for maintaining the quality and safety of food products.

2.3 Enzymatic reactions

Enzymatic reactions play a crucial role in food processing, influencing food texture, structure, sensory properties, and nutritional value. Unlike non-enzymatic browning, enzymatic browning reactions involve the action of enzymes such as polyphenol oxidase (PPO) present in food, leading to the development of undesirable color changes in fruits and vegetables (Tchoné et al., 2005). Enzymatic reactions can significantly impact food texture and structure, as crosslinking enzymes can be applied in various food processing applications to improve the texture of products such as cereal, dairy, meat, and fish products (Buchert et al., 2010). Enzymatic hydrolysis of proteins can also alter their functional properties, increasing solubility and influencing the texture and sensory attributes of food products (Wouters et al., 2016). Furthermore, enzymatic reactions can lead to the formation of glycoconjugates, which can serve as important food ingredients, improving the techno-functional properties and sensory attributes of food products (Zhou et al., 2020).

The impact of enzymatic reactions on food texture and structure is substantial, as they can influence the rheological properties, mechanical breakdown, and sensory attributes of food products. Enzymatic reactions can contribute to the breakdown of food structures in simulated gastric environments, affecting the texture and sensory properties of foods (Kong & Singh, 2009). Additionally, enzymatic hydrolysis can influence the structure, texture, and bioactive properties of proteins, leading to changes in the sensory attributes of food products (Dash & Ghosh, 2017). Enzymatic reactions can also lead to the disintegration of solid foods, affecting their texture and microstructure (Kong & Singh, 2009). Moreover, enzymatic reactions can contribute to the improvement of the texture and rheology of thermally processed and frozen fruit and vegetable products through refined manipulation of chemical and/or enzymatic pectin degradation (Buggenhout et al., 2009).

In terms of nutritional value, enzymatic reactions can have both positive and negative effects. Enzymatic hydrolysis can influence the nutritional value of proteins, altering their functional properties without reducing their nutritional value (Salleh & Zulkipli, 2021). However, enzymatic browning reactions, which are the main function of polyphenol oxidases in fruits and vegetables, can lead to unpleasant sensory qualities and losses in nutrient quality (Tchoné et al., 2005). Enzymatic reactions can also lead to the degradation or activation of nutrients, affecting the nutritional value of food products. For example, enzymatic hydrolysis can lead to the activation of antioxidant properties in food products, influencing their nutritional value (Samaei et al., 2020). Additionally, the pH of the reaction during enzymatic hydrolysis is considered one of the most important parameters, affecting the nutritional and functional properties of food products (Kleekayai et al., 2022).

In conclusion, enzymatic reactions play a significant role in food processing, influencing food texture, structure, sensory properties, and nutritional value. Understanding and controlling enzymatic reactions are essential for developing high-quality, safe, and nutritious food products.

3. Effects on Nutritional Value

The effects of food processing on nutritional value are multifaceted, encompassing the loss of vitamins and minerals, the formation of harmful compounds, and nutritional changes in processed foods. The impact of food processing on nutritional value is a critical consideration, as it directly influences the health and well-being of consumers.

Loss of Vitamins and Minerals: Food processing techniques such as boiling, roasting, and freezing can lead to the degradation of vitamins and minerals in food products (Eltom et al., 2022)Hannon et al., 2007; Gómez et al., 2020). Thermal processing, for instance, can cause a reduction in the vitamin E content of peanuts, impacting their nutritional quality (Eltom et al., 2022). Similarly, the observed large losses of water-soluble vitamins are mostly attributed to pre-freezing processes, such as blanching, which results in the leaching of vitamins and other soluble components of the food (Hannon et al., 2007). Furthermore, the voluntary addition of vitamins and minerals to foods is one way that micronutrient intakes can be increased and the risk of inadequate intakes can be reduced (Touati et al., 2016).

Formation of Harmful Compounds: Food processing can lead to the formation of harmful compounds that may have adverse effects on human health. Enzymatic browning reactions, for example, can result in the development of undesirable color changes in fruits and vegetables, leading to losses in nutrient quality. Additionally, the chemical structures of substances responsible for organoleptic characteristics or nutritional value can be affected during processing, influencing consumer acceptance and balanced diet (Kiely et al., 2001). Furthermore, the thermal processing of foods can lead to the formation of harmful compounds and the loss of nutritional value, affecting the overall quality of processed foods (Egal & Oldewage-Theron, 2019).

Nutritional Changes in Processed Foods: The nutritional value of processed foods can be altered due to various processing and preservation technologies. Enzymatic hydrolysis, for instance, can influence the nutritional value of proteins, altering their functional properties without reducing their nutritional value. Moreover, the efficacy and safety of nutritional supplement use in a representative sample of adults have been shown to influence micronutrient intakes, affecting the overall nutritional status of individuals. Additionally, the beneficial nutritional effects of extruded foods range from increased protein and starch digestibility to the retention of various micronutrients, highlighting the potential impact of food processing on nutritional quality .

In conclusion, the effects of food processing on nutritional value are diverse and can significantly impact the overall quality and safety of food products. Understanding these effects is essential for developing strategies to mitigate nutrient losses and harmful compound formation, ultimately ensuring the delivery of nutritious and safe food to consumers.

3.1 Loss of vitamins and minerals during food processing

Factors contributing to nutrient loss during food processing can include exposure to heat, light, air, and water, as well as mechanical processing and storage conditions (Severini et al., 2015)Steur et al., 2016; Tipton, 2015). For example, the increase of treatment time caused a vitamin C decrease in samples blanched by boiling water and steam, which was not observed in microwaved samples, highlighting the impact of processing methods on nutrient retention (Weaver et al., 2014). Additionally, the bioavailability of nutrients depends on many factors, including physicochemical properties of nutraceuticals, kind of food matrix, processing, and storage conditions (Severini et al., 2015). The pathways and magnitude of nutrient losses are not well quantified, and the nutrient losses that could occur at this stage were mainly due to overbaking of bread and inappropriate peeling, washing, and pasteurization of peaches (Kachhadiya et al., 2018; Eicher-Miller et al., 2015).

Examples of commonly lost nutrients during food processing include vitamins such as vitamin C, thiamine, and riboflavin, as well as minerals such as potassium and calcium (Assohoun et al., 2013; Weaver et al., 2014; Eicher-Miller et al., 2012). For instance, the superior nutritional quality of microwaves blanched samples is evident due to avoidance of leaching losses during processing, highlighting the impact of blanching methods on nutrient retention (O'Mahony et al., 2023). Furthermore, processed foods contribute significantly to nutrient intakes, with 66% to 84% of total daily energy, saturated fat, cholesterol, fiber, total sugar, added sugars, calcium, vitamin D, potassium, and sodium intake being contributed by processed foods (Pachón et al., 2021).

Strategies to minimize nutrient loss during processing can include the use of innovative technologies, such as fermentation, to reduce the concentration of total aflatoxins and the most important reduction in aflatoxin B1, as well as the application of fortification to improve the nutritional quality of foods. Additionally, the reformulation of processed foods over time has been identified as a strategy to reduce sodium, salt, and sugar content in breakfast cereals, contributing to improved nutritional quality . Moreover, the potential contribution of fortified maize flour, oil, rice, salt, and wheat flour to estimated average requirements and tolerable upper intake levels for 15 nutrients in 153 countries has been highlighted as a strategy to address nutrient deficiencies .

In conclusion, nutrient loss during food processing is influenced by various factors, and the retention of nutrients can be improved through the application of appropriate processing methods and fortification strategies.

3.2 Formation of harmful compounds

Food processing can lead to the formation of potentially harmful compounds, which may have adverse effects on human health. These compounds can be generated through various chemical reactions, such as the Maillard reaction, lipid oxidation, and thermal processing. The presence of these harmful compounds in processed foods has raised concerns regarding their potential impact on consumer health and safety.

One example of a harmful compound formed during food processing is acrylamide, which is produced in the Maillard reaction. Acrylamide has been classified as probably carcinogenic in humans and has been found in a range of fried and oven-cooked foods, raising worldwide concern due to its potential health risks Mottram et al. (2002). Another example is the formation of potentially carcinogenic compounds, such as polycyclic aromatic hydrocarbons (PAHs), during the heating and processing of foods. PAHs have been identified as carcinogens and are a cause for food safety concern (Wang et al., 2022). Additionally, the formation of mycotoxins, such as aflatoxins, during the processing and storage of food products can pose significant health risks, including hepatotoxicity and carcinogenicity (Sandlin et al., 2021).

Several strategies can be employed to minimize the formation of harmful compounds during food processing. These include the optimization of processing parameters to ensure food safety and maximize food quality, as well as the use of innovative technologies to reduce the concentration of harmful compounds. For example, the use of ozonation treatments has been explored as a method to reduce the concentration and toxicity of harmful compounds, such as benzoapyrene, in smoked fish products (Rozentale et al., 2016). Additionally, the application of nanosensors and nanopackaging materials has been suggested as a means to enable rapid and reliable detection of microbial contamination, harmful chemicals, and pesticides, thereby minimizing their presence in food products (Yu et al., 2018). Furthermore, computational biology tools have been utilized to discover and optimize the enzymatic removal of mycotoxins, offering a potential strategy to mitigate the presence of harmful compounds in food (Sandlin et al., 2021).

In conclusion, the formation of harmful compounds during food processing poses significant challenges to food safety and consumer health. Employing strategies to minimize the presence of these compounds is essential for ensuring the safety and quality of processed foods.

3.3 Nutritional changes in processed foods

Processed foods undergo various alterations that can impact their nutritional profiles, leading to differences in nutrient content compared to unprocessed foods. These changes are influenced by factors such as the type of processing, food composition, and storage conditions. Understanding these nutritional changes is essential for assessing the overall health impact of processed foods.

Studies have shown that processed foods often exhibit higher energy density, overall fat content, saturated and trans fat, and free sugar, while containing less fiber, protein, sodium, and potassium compared to unprocessed or minimally processed foods Louzada et al. (2015). Processed foods are also associated with lower levels of bioactivity of nutrients compared to raw and unprocessed foods (Singh, 2018). Additionally, ultra-processed foods have been found to have suboptimal nutritional profiles, highlighting the differences in nutrient content between processed and unprocessed foods (Habibi et al., 2022).

The nutritional changes in processed foods are influenced by various factors, including the type of processing, food handling, and environmental conditions. For example, the use of different processing methods, such as heating, can lead to the degradation of nutrients, affecting the overall nutritional quality of the final product (Oviedo-Solís et al., 2022). Additionally, the impact of climate trends, such as changes in rainfall and temperature, has been associated with the consumption of processed and unprocessed foods, influencing their nutritional content (López-Olmedo et al., 2021). Furthermore, the lack of nutrient declarations and low nutritional quality of pre-packaged foods sold in supermarkets has been identified as a factor contributing to the nutritional changes in processed foods (Alarcon-Calderon et al., 2020).

Several strategies have been proposed to enhance or preserve the nutritional value of processed foods. These include the use of innovative technologies, such as cold plasma, to preserve the nutritional quality of aquatic food products, as well as the evaluation of foods, drinks, and diets according to the degree of processing for nutritional quality, environmental impact, and food costs (Moubarac et al., 2012; Moreira et al., 2015). Additionally, the use of natural preservatives and the application of fermentation have been suggested as methods to extend the longevity of food products while maintaining their nutritional value (Nair et al., 2019). Furthermore, the development of a novel processed food classification system has been proposed to identify and assess the nutritional quality of processed foods, contributing to improved dietary quality and consumer education (Vellinga et al., 2022).

In conclusion, the nutritional changes in processed foods are influenced by various factors, and employing strategies to enhance or preserve their nutritional value is essential for promoting healthier dietary choices and improving overall public health.

4. Conclusion

Chemical reactions and transformations play a pivotal role in food processing, driving the development of various food products. These reactions encompass a myriad of processes such as the Maillard reaction, enzymatic reactions, and oxidation reactions, which are essential for enhancing food safety, extending shelf life, and improving nutritional quality. The effects of these chemical reactions on nutritional value are significant, as they can lead to the formation of harmful compounds, the loss of vitamins and minerals, and alterations in the nutritional composition of processed foods. For instance, the Maillard reaction can lead to the formation of advanced glycation end products (AGEs), while oxidation reactions can result in the degradation of essential nutrients and the formation of toxic compounds. Understanding and optimizing food processing techniques are crucial for maximizing the nutritional benefits of processed foods. By comprehensively studying the chemical reactions and transformations occurring during food processing, it is possible to develop strategies to minimize the formation of harmful compounds, retain essential nutrients, and enhance the overall nutritional quality of processed foods. This knowledge is essential for ensuring that processed foods contribute to a healthy and balanced diet, ultimately benefiting consumer health and well-being.

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