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Role of Enzymes in Food Processing

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Enzymes are very important in the food industry because they naturally speed up and improve various processes. They are used in many areas, including baking, dairy, brewing, and the processing of fruits and vegetables. Enzymes help make food products better in quality, longer-lasting, more stable, and tastier. In baking, enzymes like amylases, proteases, and lipases are essential. Amylases turn starches into sugars, which feed the yeast and help the dough rise more effectively. Proteases change gluten, making the dough easier to work with. Lipases improve the texture and softness of the bread, helping it stay fresh for a longer time. In dairy processing, enzymes such as rennet and lactase are crucial. Rennet is a mix of enzymes used in cheese-making to coagulate milk, which leads to the creation of curds and whey. Lactase breaks down lactose into glucose and galactose, making dairy products suitable for people who are lactose intolerant. These enzymatic actions not only improve the nutritional value of dairy products but also enhance their digestibility and flavouring, in the brewing industry, enzymes like amylases, proteases, and glucanases are used to convert starches into fermented sugars, break down proteins for better clarity, and lower viscosity. These enzymes help with efficient fermentation, resulting in higher alcohol yields and better beer quality. Additionally, β-glucanase helps break down β-glucans, which can cause problems during filtration, thus improving the overall brewing process. When it comes to processing fruits and vegetables, enzymes such as pectinases, cellulases, and hemicelluloses play important roles. Pectinases break down pectin, a key component of plant cell walls, leading to clearer juices and more efficient juice extraction. Cellulases and hemicelluloses

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further assist by breaking down cell walls, which helps release valuable nutrients and improves the texture of the processed products. Enzymes are essential in the food processing industry, providing numerous benefits such as better product quality, longer shelf life, increased nutritional value, and greater efficiency in production. Their ability to work under mild conditions, along with their specificity and biodegradability, makes them ideal for sustainable food production. Continuous research and the development of new enzymes and their applications will keep transforming the industry, leading to healthier, safer, and more sustainable food products.

Keywords: Enzymes; proteins; food processing; production.

1. INTRODUCTION

The term "enzyme" originates from the Greek words "en" (meaning in or within) and "zyme" (meaning leaven or yeast) (Robinson, 2015). Enzymes are biological catalysts produces by living things that have amazing attributes and significant roles in controlling biochemical processes (Abdullahi et al, 2021). Enzymes are beneficial catalysts for biological reaction because of their ideal substrate selectively and remarkable catalytic power. Enzymes can be described as soluble, colloidal, and organic catalysts generated by living cells, yet capable of functioning independently of those cells (Bhatia and Bhatia, 2018). Because they act as catalysts to change basic materials into better food products, enzymes have become essential for food technology. The properties of enzymes are chemical and biological. Due to their capacity to catalyse chemical processes, they can also play a biological role in metabolic pathways and networks (Cuseta et al, 2014). Their structures and sequences define their place in the genome and proteome of all living things. Enzymes in food processing are added to food to change its properties. Enzymes for food processing are utilized in the production of pre-digested meals, milk products, meat products, and starch products (Chaudhary Sagar et al, 2015). Chemical reaction can occur more quickly when enzymes are present because they lower the activation energy needed for such reaction. During the food processing process, this essential property of enzymes is used to improve the texture, flavour, nutritional value, and shelf life of food products among other goals (Fernandes and Carvalho, 2016). Enzymes can be described as soluble, colloidal, and organic catalysts generated by living cells, yet capable of functioning independently of those cells (Chaudhary Sagar et al, 2015). Microbial enzymes are crucial in the food industry due to their greater stability compared to plant and animal enzymes. They can be produced economically and efficiently through fermentation, requiring less time and space. Their consistent performance also simplifies the process of adjusting and enhancing production methods (Raveendran et al, 2018). Enzyme immobilization is a method that helps keep enzymes stable, making it possible to use them multiple times and even add them to packaging. This technique allows enzymes to be gradually released into food, which can enhance specific qualities of certain products (Almasi et al, 2021).

2. STRUCTURE OF ENZYMES

Enzymes not only catalyse reactions but also share many physicochemical properties with proteins, including solubility, electrophoretic behaviour, electrolytic properties, and chemical reactivity (Bhatia et al, 2018). The primary structure and catalytic function of an enzyme are determined by its chain of amino acids linked by peptide bonds, forming a protein molecule. Folding of this chain gives rise to its secondary structure, while its complete folding results in its tertiary structure. Some enzymes consist of multiple folded chains, forming their quaternary structure (Copeland, 2023). Enzymes belong to various classes & the classification of enzymes is depicted in Table 1.

Table 1. Classes of enzymes

Classes of enzymes	Examples	Role	Referrences
Oxidoreductases	Lactate dehydrogenase	Catalyses oxidation-reduction reactions	(Mousavi et al, 2021)
Transferases	Nucleoside monophosphate kinase (NMP kinase)	Transfer groups from the substrate to acceptor molecules (except hydrogen and water)	(Herbinger et al, 2016)
Hydrolases	Alkylhalidase, Asparaginase	Catalysis's reaction by adding water molecules, resulting in	(Shukla et al, 2022)

Classes of enzymes	Examples	Role	Referrences
		breaking of several chemical bonds	
Lyases	Fumarase	Enzymes that add or remove functional groups to create or break double bonds in molecules.	(Khare and Yadav, 2015)
Isomerases	Triose phosphate isomerase	Isomerization involves the transfer of groups within a molecule, resulting in the formation of different isomers.	(De Souza Vandenberghe et al, 2020)
Ligases	Amino-acyl t-RNA synthetase	Ligases are enzymes that help link two substrates together by utilizing energy from ATP.	(Bhatt, 2023)

3. TYPES OF ENZYMES IN FOOD PROCESSING

Enzymes utilized in the food industry come from plants, animals, or microorganisms. These food enzymes help in the digestion and breakdown of food, as well as accelerate food processing (Table 2) and enhance the quality of food products (Yang et al. 2023). Amylase, protease, ligase, oxidoreductase, and isomerase, play crucial roles in food processing within the industry (Raveendran et al, 2018). Boosting the production of food enzymes is very important for advancing the food industry. It helps lower production costs, improve product quality, simplify processing, meet market demands, and make companies more competitive (Wu et al. 2021).

Table 2. Potential uses of Enzymes in various food sectors

S. no.	Enzymes	Source of enzyme	Class	Uses	References
1	Pectinase	Fungi, bacteria, yeast	Hydrolase	Filtration, and tea fermentation, oil extraction, clarification of fruit juices	(Haile and Ayele 2022)
2	Amylase	Bacteria, fungi, malt	Hydrolase	starch conversion, baking, brewing	(Ahmad et al, 2019)
3	Lactase P(Beta-galactosidase)	Yeat, bacteria	Hydrolase	fermentation	(Jones et al, 2017)
4	Protease	Bacteria, fungi, fungi	Hydrolase	Meat tenderization, coagulation of milk, brewing	(Solanki et al, 2021)
5	cellulase	Fungi, bacteria	Hydrolase	Cellulose hydrolysis, fruit, and vegetable clarification	(Ejaz et al, 2021)
6	Invertase	Yeast, bacteria, fungi	Hydrolase	Preventing Crystallization, fermentation	(Manoochehri et al, 2020)
7	Rennin (Chymosin)	Animals, fungus	Lyases	milk coagulation	(Aljammas et al, 2018)
8	Glucose Isomerase	Bacteria, yeast, fungus	Isomerase	Production of high fructose corn syrup (beverage sweetener)	(Chaudhary Sagar et al, 2015)
9	Alpha-amylase (Takadiastase)	Bacteria, fungi	Hydrolase	Baking industry, corn processing, beverage industry, sugar industry	(Far et al, 2020)
10	Catalase	Bacteria, yeast, fungi	oxidoreductases	Removal of hydrogen peroxide	(Kimoto et al, 2012)
11	Lipase	Bacteria,	Hydrolases	Fat modification,	(Guerrand,

S. no.	Enzymes	Source of enzyme	Class	Uses	References
		fungi		hydrolysing triglycerides in oils	2017)
12	Esterase	Bacteria, fungi	Hydrolase	De-esterification of dietary fibre, production of flavour esters	(Xu et al, 2017)
13	Asparaginase	Fungi, bacteria	Hydrolase	Lowering acrylamide production during baking, anti- cancerous	(Krishnapura et al, 2016)

Amylase: Another name for amylase is "glycoside hydrolase." α-Amylases are enzymes that break down starch by breaking down the α-1,4 glycosidic linkages in polysaccharides. This process produces short-chain dextrin (Sindhu et al, 2017). α-amylases are widely used in the food sector for liquefaction of starch, baking, brewing, and as digestive aids. They are extensively employed in the baking sector as an antistaling agent and flavour enhancer to raise the quality of bread. α-amylases are added to the dough during baking to help break down starch into smaller dextrins, which yeast then ferments. It enhances the Flavour, colour of the crust, and consistency of bread (Hong et al, 2023). These are utilized in the making of rice cakes and other powdered meals as a glazing ingredient. The starch liquefaction process, which turns starch into glucose and fructose syrups, is also used in the starch business. α-amylases derived from Bacillus amyloliquefaciencs, Bacillus stearothermophilus, or Bacillus licheniformis are responsible for most of the starch saccharification (Klinfoong et al 2022). α-amylases are also used in the clarification of fruit juices, where they work in combination with cellulases and pectinases to increase yield and lower processing costs (Kumar, 2015).

Amylase, which breaks down starch into sugars, has the following optimal conditions:

Optimal Temperature: 50–60°C (for human salivary and pancreatic amylases)

Optimal pH: 6.7–7.0 (neutral to slightly alkaline)

Factors Affecting Activity:

- Amylase activity declines sharply when the temperature deviates significantly from the optimal range.

- Extreme pH levels, either acidic or alkaline, can denature the enzyme or reduce its efficiency (Fu et al, 2022).

Protease: Enzymes termed proteases are responsible for catalysing the breakdown of peptide bonds found in proteins and polypeptides. They are primarily utilized in food and pharmaceuticals, then detergents. sectors. They make up 60% of the commercially available industrial enzymes (Singh et al, 2016). Based on where they act on polypeptide chains, proteases are classified as either endopeptidases or exopeptidases. Endopeptidases randomly act in the central regions of polypeptide chains, while exopeptidases act on the ends of polypeptide chains (Li et al, 2013). The food industry uses plant proteases including bromelain, ficin, and papain extensively for a variety of purposes include brewing, meat tenderization, milk coagulation and as a digestive supplement Moreover, proteases are utilized to alter the coagulation and emulsification processes as well as to add the flavour, nutritional value, solubility, and digestibility of food proteins (Aruna et al, 2014). In the baking industry, proteases are frequently utilized in the creation of bread, baked goods, crackers, and waffles. These enzymes are used to shorten the time needed to mix dough, lessen homogeneity and consistency, control the strength of the gluten in bread, and enhance texture and flavour (Miguel et al, 2013). Aspergillus usamii's acid protease has been effectively used to enhance the functional qualities of wheat gluten (Deng et al, 2016). Naturally occurring proteases play a major role in the flavour variations of cheeses. They are used to change the functional characteristics, reduce the allergenic potential, and quicken the ripening of cheese characteristics of dairy products (Raveendran et al, 2018).

Protease, which breaks down proteins into peptides and amino acids, has the following optimal conditions:

Optimal Temperature: 40–60°C (this varies depending on the type of protease; thermophilic proteases can function at higher temperatures)

Optimal pH:

Pepsin (acidic protease): pH 1.5–2.5 (found in the stomach)
Trypsin (alkaline protease): pH 7.5–8.5 (found in the small intestine)
Bromelain (from pineapple): pH 4.5–5.5 (Kaur et al, 2020)

Pectinase: Enzymes termed pectinases catalyse the breakdown of glycosidic linkages that occur in pectic polymers. This enzyme's natural substrate is pectic compounds, which can be found in citrus fruits including tomato, pineapple, orange, apple, lemon pulp, orange peel, and others (Ozojiofor and Rasheed, 2024). There have been efforts to improve the thermal stability and yield of pectinases that can be created from both naturally occurring and recombinant microorganisms. Pectinases are used in a wide range of industrial processes, including cleaning up food processing, and paper bleaching (Anand et al, 2020). Pectinase-added juices seem clearer and are easier to filter than their counterparts with reduced enzyme levels. Juices become thick and dark after adding gelatin and pectin, and the most expensive step in the process is clearing the haze. For optimal results, the employment of biogenic enzymes, including pectinases, in juices would work almost nine times better than mechanical processing (Bajpai et al, 2018). Its optimal temperature range is typically between 40–60°C, although some microbial sources of pectinase can operate at even higher temperatures. The enzyme is most active in slightly acidic conditions, with an optimal pH range of 4.5–5.5. While higher temperatures generally enhance enzyme activity, excessive heat can lead to denaturation and a loss of function. Pectinase is most efficient when the pectin structure is in a more easily hydrolyzable state, which is favored by its optimal pH range (Rehman et al, 2021).

Asparaginase: As the name indicates, asparaginase is an asparagine-depleting enzyme since it catalyses the breakdown of asparagine into the acid derivative aspartic acid and NH_3. Although asparagine is an important amino acid for malignant cells, it is not necessary for humans (Rathore et al, 2022). As a result, the proliferation of malignant cells is significantly impacted by asparagine depletion, which is the basis for the enzyme's anticancer properties. (Aghaeepoor et al, 2018). A variety of food processing techniques, including baking, and frying in oil, turn asparagine into acrylamide, a known carcinogen. The depletion of asparagines by enzymatic treatment has been proven to be an efficient method among several approaches trying to overcome the acrylamide formation, lowering the formation of acrylamides from asparaginase by 97% (Andrade et al, 2021).

Its optimal temperature range is between 37–50°C, which is typical for most sources of the enzyme. Additionally, asparaginase performs best at a pH range of 7.0 to 8.0, which is neutral to slightly alkaline. The enzyme is particularly active at physiological temperatures, around 37°C, and although it generally favors neutral to slightly alkaline pH, some sources of asparaginase may exhibit increased activity in slightly acidic conditions (Kaur et al, 2020).

Esterase: Esterase is useful in the splitting of esters into acid and alcohol in aqueous solutions. The food and beverage industries depend extensively on esterase, which are mostly employed to alter the oil and fat content of different fruit juices as well as to create scents and Flavors. (Rathore et al, 2022) Esterases are widely used in the food and beverage industries; they are mostly used to change the oil and fat content of various fruit juices and to add tastes and smells. The fruity flavors found in cheese are caused by various short-chain fatty acid methyl or ethyl esters. It has been documented that bacteria can produce thioesters and ethyl esters (Kumar et al, 2012).

4. APPLICATION IN FOOD PROCESSING

4.1 Dairy Industry

For the processing of cheese, yogurt, milk, and milk products, dairy enzymes are used. These enzymes' functions range widely from coagulant to bioprotective enzymes that extend the shelf life of dairy products (Selamoglu, 2020). Enzymes such as lipases, proteases, esterase, lactases, and catalase are widely used in dairy and food technology. Rennet, sometimes referred to as rennin, is a mixture of chymosin and pepsin that is taken from microbial and animal sources and is used as the first step in the cheese-curdling process (Patel et al, 2016).

In the dairy industry, various enzymes play crucial roles in enhancing dairy products. Rennet, a complex enzyme primarily composed of chymosin, is essential for coagulating milk. It breaks down casein, a milk protein, which helps form curds (solid) and separates them from the whey (liquid) during cheese-making (McCain et al, 2018). Lactase is another important enzyme that breaks down lactose, the sugar in milk, into glucose and galactose. This enzyme is vital for creating lactose-free dairy products for those who are lactose intolerant and improves the taste and digestibility of dairy items (Sarim et al, 2020).

Lipase helps in the breakdown of fats into glycerol and free fatty acids, which is particularly useful in cheese-making. It helps develop unique Flavors by accelerating fat breakdown and contributing to the maturation process (Niamah et al, 2023). Similarly, proteases break down proteins into smaller peptides and amino acids, aiding in the ripening and flavour development of cheese. Peptidases further break down these peptides into amino acids, which helps refine cheese texture and taste (Stock and Wells, 2023).

Alpha-amylase breaks down starches into simpler sugars, which helps reduce the viscosity of dairy products like yogurt by dissolving any added starches (Niamah et al, 2023). Beta-galactosidase also breaks down lactose, ensuring that lactose is fully dissolved in lactose-free dairy products, making them suitable for lactose-intolerant individuals (Stock and Wells, 2023). Lastly, xylanase breaks down xylans, polysaccharides found in plant cell walls, which can help reduce viscosity and improve the texture of dairy products like yogurt. (Evershed et al. 2022).

4.2 Beverage Industry

Brewing generally follows nine stages: malting, milling, mashing, lautering, hopping, fermentation, conditioning, filtering, and then canning or bottling (Gomaa, 2018). In brewing, a variety of enzymes like amylase, glucanase, protease, glycosidase, pectinase, and phytase are used at different stages to enhance both the efficiency and quality of beer production. On the other hand, in winemaking, enzymes such as lipase, lysozyme, pectinase, glucanase, glycosidase, urease, protease, phenol oxidase, ester hydrolase, and synthetase are utilized to develop the wine's complex flavour and aroma characteristics (Pati and Samantaray, 2022).

In beverage production, especially in brewing and winemaking, various enzymes are essential for enhancing the quality and efficiency of the final product. Alpha amylase helps by breaking down starches into simpler sugars during malting and brewing, while Beta amylase creates maltose, which yeast ferments to produce beer and whiskey (Claus and Mojsov, 2018) Cellulase assists in extracting juice and reducing viscosity, making it particularly useful in processing fruit juices and wines (Hossain and Ahmed, 2023). Pectinases work on pectin in plant cell walls, which helps to clarify fruit juices and wines by reducing cloudiness and improving texture (Uzuner and Cekmecelioglu, 2019). Glucoamylases convert complex sugars into glucose, which is crucial for fermenting spirits and other alcoholic beverages (Paramithiotis et al, 2022). Proteases break down proteins that can cause haze in beer and wine, improving both clarity and stability while enhancing flavour and texture (Raveendran et al, 2018). Hemicelluloses aid in breaking down hemicellulose, which helps with juice extraction and reduces consistency issues in fruit juices (Krieger-Weber et al, 2020). Invertase turns sucrose into glucose and fructose, boosting sweetness and improving the texture of certain beverages (Ottone et al, 2020). Lipases break down fats, which helps in cleaning equipment by breaking down organic residues (Ray and Rosell, 2017). Beta-glucanase makes it easier to filter wort during beer brewing by breaking down beta-glucans and tanninases reduce bitterness and enhance the taste of beverages by breaking down tannins. (Cosme et al, 2023).

4.3 Meat Industry

Meat aging involves a lot of changes that start in the animal's muscle after it is slaughtered. This process leads to improvements in colour, tenderness, and aroma of the meat. Enzymes are essential in the meat industry because they help in preparing meat, making it more tender, improving its flavour, and keeping it fresh (Lonergan et al, 2018). The processes of enzymatic glycolysis, proteolysis, and lipolysis are important in the conversion of muscle into meat (Wang et al, 2022).

Proteases, such as papain from papayas, bromelain from pineapples, and ficin from figs, are crucial in meat processing for tenderizing meat. They work by breaking down muscle proteins, which enhances the meat's texture and tenderness (Abril et al, 2023). Lipases break down fats into free fatty acids and glycerol, playing a key role in developing specific flavors in aged meats and processed products like dry-cured hams and salamis. They contribute to flavour development through the breakdown of fats. (Khan et al, 2016) Transglutaminase, often called "meat glue," is used to bind meat pieces together by forming covalent bonds between proteins. This improves the texture and appearance of processed meats. (Ma et al.,2019). Alpha-amylase breaks down starches into simpler sugars and is used in meat processing to modify texture and enhance flavour, especially in products where starches serve as fillers (Salmerón et al, 2015). While lactase is not directly used in meat processing, it can help reduce lactose in dairy-based meat products, like certain marinades or sauces, improving their flavour (Chauhan and England, 2018). Collagenase breaks down collagen, a protein found in connective tissue, making tougher cuts of meat more tender and easier to cook by turning collagen into gelatin (Han et al, 2014). Catalase helps control oxidative reactions by breaking down hydrogen peroxide into water and oxygen, thus extending the shelf life of meat by reducing oxidative spoilage (Hu et al, 2020).

5. FRUIT AND VEGETABLES (EXTRACTION AND PRESERVATION)

During the processing of fruits and vegetables, various types of enzymes, including pectinase, cellulase, amylase, tannase, and amyl glucosidase, are used. The breakdown of cell wall in the fruits and vegetables, the release of liquids and sugars, and the improvement of the storage period of the processed food products are done by these enzymes (Basheer et al, 2022. In the processing of fruits and vegetables, several endogenous and newly developed enzymes are used. The texture, colour, flavour, and taste attributes of the processed products are significantly influenced by the enzymes present in the fruits and vegetables (Heirangkhongjam et al, 2022).

In the extraction and processing of fruits and vegetables, several enzymes are used to enhance the product quality. Pectinase breaks down pectin in cell walls, which boosts juice yield and clarity, and makes fruit pulp less thick, making it easier to process (Heirangkhongjam et al, 2022). Cellulase breaks down cellulose, which softens fruits and vegetables, making juice extraction more efficient and improving the texture and yield by reducing fibrous materials. Amylase converts starch into simpler sugars like maltose and glucose, boosting sweetness, flavour, and texture, making it ideal for fruit-based beverages and jams (Temiz and Ayhan, 2017). Proteins are broken down into peptides and amino acids by protease, which aids in the tenderizing of produce, improves texture, and reduces cooking times. Moreover, juices are clarified and bitterness is reduced by this enzyme (Sumonsiri and Barringer, 2014). Lipase breaks down fats into fatty acids and glycerol. It helps control fat content, improving the texture and flavour of fatty products. Tannins are hydrolysed by tannase, which improves the flavour and colour of fruit and vegetable products by reducing bitterness and astringency. This is especially beneficial in fruit juices and wines. The oxidation of glucose to gluconic acid and hydrogen peroxide is catalysed by Glucose Oxidase, which helps to reduce glucose levels, extend shelf life, and preserve freshness. It is often used alongside other enzymes to manage sugar content and stabilize products (Basheer et al, 2022).

6. BAKING INDUSTRY

Enzymes play a vital role in baking, each contributing to the quality and characteristics of the final product. Amylase enhances dough rise and fermentation by converting starches into sugars, resulting in a better crust and a softer texture (Miguel et al, 2013). Meanwhile, protease breaks down proteins to promote gluten production, increasing the dough's adaptability and improving the crumb structure (Zhou et al, 2014). Lipase works by breaking down fats into free fatty acids, which not only enhances flavor and dough stability but also improves shelf life and texture (Struyf et al, 2017). Xylanase boosts the hemicellulose in flour, leading to better dough elasticity and water absorption, which ultimately enhances the volume and texture of bread (Olaerts et al, 2016). Cellulase further supports this by improving crumb structure and making dough handling easier, especially in whole grain products. For those with lactose intolerance, lactase is essential as it breaks down lactose in dairy ingredients, making baked goods more accessible (Leys et al, 2016). Finally, glucose oxidase strengthens and stabilizes the dough, benefiting the overall texture and extending the shelf life of bread. Together, these enzymes work harmoniously to create high-quality baked goods that delight consumers (Rees et al, 2018).

7. FUTURE PROSPECTS

The use of novel enzymes is set to significantly enhance the quality and texture of baked goods. For example, transglutaminase fortifies dough, improving crumb structure and rise, which allows for the creation of more sophisticated and appealing products (Sangster et al, 2022). Additionally, enzymes like phytase can increase the bioavailability of essential minerals in whole grains, catering to the growing consumer demand for healthier, nutrient-dense options. On the sustainability front, enzymes can reduce waste and improve resource efficiency by breaking down plant by-products more effectively, leading to a more sustainable production process (Sharma et al, 2021).

Flavor development is also benefiting from enzymes such as laccase and glutaminase, which add richness and complexity to baked goods, appealing to consumers looking for artisan and gourmet flavors (Singh et al, 2016) Moreover, enzymes like invertase play a crucial role in enhancing shelf life by preventing staleness and improving moisture retention, making products last longer without the need for artificial additives (Choi et al, 2015).

Health benefits are another area of focus, with enzymes like lactase addressing dietary needs by increasing digestibility and reducing allergens, aligning with the trend toward healthier eating (Solano, 2015). Advances in enzyme technology allow manufacturers to customize enzyme blends for specific applications, fostering innovation and meeting diverse consumer preferences. Ongoing research into new enzymes and their mechanisms is likely to yield exciting discoveries, while evolving regulatory frameworks will open doors for broader applications, creating new markets and opportunities in the food industry (Jemli et al, 2016, Copeland, 2023, Brumano et al., 2019).

8. CONCLUSION

In conclusion, enzymes are vital players in food processing, making a real difference in the quality, flavor, texture, and nutrition of products across various industries. They work wonders in areas like dairy production, brewing, meat processing, and baking. For example, amylase helps improve dough elasticity and fermentation, while proteases make meat more tender and flavourful. With more consumers looking for healthy and sustainable options, enzymes are stepping up to meet those needs. Enzymes like phytase enhance the availability of essential minerals in whole grains, aligning with the trend toward healthier eating. Additionally, enzymes such as invertase help extend shelf life and keep moisture in, cutting down the need for artificial additives. As research continues, we can expect to discover new enzymes and improve existing ones, leading to even greater efficiency in food processing. Changing regulations may also open new possibilities for enzyme applications, expanding their role in the market. Overall, the future of food processing looks promising, with enzymes paving the way for better quality, sustainability, and health benefits. This not only boosts consumer satisfaction but also enhances competitiveness in the industry.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

We hereby declare that no generative AI technologies such as large language models (ChatGPT, COPILOT, etc,) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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