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Role of Bacteria and Yeast in Fermentation

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Abstract: Fermentation processes using bacteria and yeast are key in numerous industries and have great relevance for human health outcomes, too. As this review article discusses the various applications and benefits of fermentation research in different sectors, we will focus on recent progress in industrial processes and potential academic impacts. The review sets out several examples of research on levels that range from single microbes to entire populations. It also studies the role of compounds in fermentation-foods and beverages. Key references cited here underscore such salient points as the need for an understanding of microbial dynamics in fermentation processes, role of probiotic microorganisms, microbial source tracking and development synthetic microbial consortia for optimal fermentation outcomes. In addition, the review explores the effects of fermentation on food safety, shelf-life extension, and the development of functional products. This insight highlights the vital role that microbial interactions play in shaping fermentation processes. And it suggests the possibility of both product improvement and improved health outcomes if we learn more about these interactions. This article gives an in-depth exploration of how bacteria and yeast are used in fermentation, from the given situations and changes that come about.

Keywords: *Fermentation, Bacteria, Yeast, Microbial dynamics*

1. Introduction

I. Introduction

Fermentation is the process in which carbohydrates, such as sugars and starches, are converted by microorganisms like yeast and bacteria into alcohol, organic acids or some gases. This metabolic process takes place under anaerobic conditions and is thus indispensable for the generation of energy (Tesnière, 2019). It is also useful in various industries to produce an array of products. Bacteria and yeast, which possess unique metabolism capabilities, are pivotal players in the fermentation of liquor. Saccharomyces cerevisiae, or baker's yeast, is widely used in fermentation for its ability to change sugar into alcohol and carbon dioxide (Zapaśnik, Sokołowska, & Bryła, 2022). This stage is crucial to produce alcoholic beverages like beer and wine. Lactic acid bacteria such as *Lactobacillus* and *Pediococcus* species play a huge role in the fermentation of dairy things - like yogurt and cheese. These bacteria enhance the flavor of food, improve its texture, and extend its shelf life (Comitini, Agarbati, Canonico, & Ciani, 2021).

An array of processed products come from the food and beverage industry where fermentation is fundamental. Soy sauce and fermented vegetables, are in some way dependent on the process for flavor, texture and storage life (Coral-Medina et al., 2022). In medicine, fermentation (cultivation of a little micro-organism called a microbe to obtain an active material) is used to produce antibiotics, enzymes and therapeutics such as an interferon. As specific micro-organisms are cultivated in large quantities, it can be done in a highly efficient way. In biotechnology, fermentation is used for the production of biofuels, bioplastics and similar things (Pawar & Rathod, 2020). This process is sustainable for manufacturing, and a demonstration of the diverse applications which fermentation technology can play in solving environmental as well as economic problems (Pérez-Alvarado et al., 2022).

Bacteria and yeast are the role - players in fermentation process that convert organic compounds into various products Lactic acid bacteria (LAB) and acetic acid bacteria (AAB) as well as yeast play a key role in fermentation, from the kick-off phase to later progression (Bayoumy, Mulder, Mol, & Tushuizen, 2021). Research has shown that the presence of yeast and LAB in a well-balanced microbial consortium is essential for efficient fermentation of substrates such as cocoa beans where lactic acid and ethanol produced by these microorganisms make a significant contribution to the overall process of the Microbial succession from yeasts to lactic acid bacteria and finally acetic acid bacteria during cocoa bean fermentation is essential for prototypical flavors in chocolate production (De Vuyst & Leroy, 2020). Yeasts predominate as the fermentation begins, followed by LAB and AAB as it continues, revealing the varied roles of different microorganisms across a spectrum. The ability of these microorganisms to break down substrates such as sugars into lactic acid by bacteria or alcohol by yeast is fundamental to the fermentation process (Fatima et al., 2023). Moreover, the microbial diversity and population dynamics of LAB and AAB in cocoa bean fermentation confirm the complex interplay between various bacterial species and their involvement in the fermentation (Schwan, Bressani, Martinez, Batista, & Dias, 2023).

Fermentation is seen in the different industrial activities that help in producing enormous products having significant applications. In the food industry, fermented foods help in the preservation of food, improving the color and taste of the product (Šikić-Pogačar, Turk, & Fijan, 2022). Moreover, fermented foods when consumed will be helpful for enhancing the health of individuals. By taking a few examples such as traditional fermented products of Zambia, that include Mabisi, Chibwantu, and Munkoyo Schoustra (Habib et al., 2023). Similar is the case with table olives which are fermented using starter cultures that are helpful in improving the taste and texture of olives and also the storage of olives for longer time without loss of freshness (Cuevas-González et al., 2022). On the other hand, the biotechnological application of yeast is nothing but the fermentation of natural flavor and fragrance molecules using Kluyveromyces marxianus. In the pharmaceutical and environmental sector, using fermentation processes increases the generation of different enzymes like carboxymethyl cellulase from *Bacillus megaterium* and the removal of sulfonamides using anaerobic fermentation will increase the microbial community (Zhou et al., 2022). In the agricultural field, fermentation residues are used as fertilizers during farming activity. In addition to the above industrial applications, fermentation acts as a beneficial process improving the gut microbiota and health of humans (Mendes Ferreira & Mendes-Faia, 2020). It can be concluded that fermentation is one of the important processes for industrial applications and increases the quality and quantity of a product.

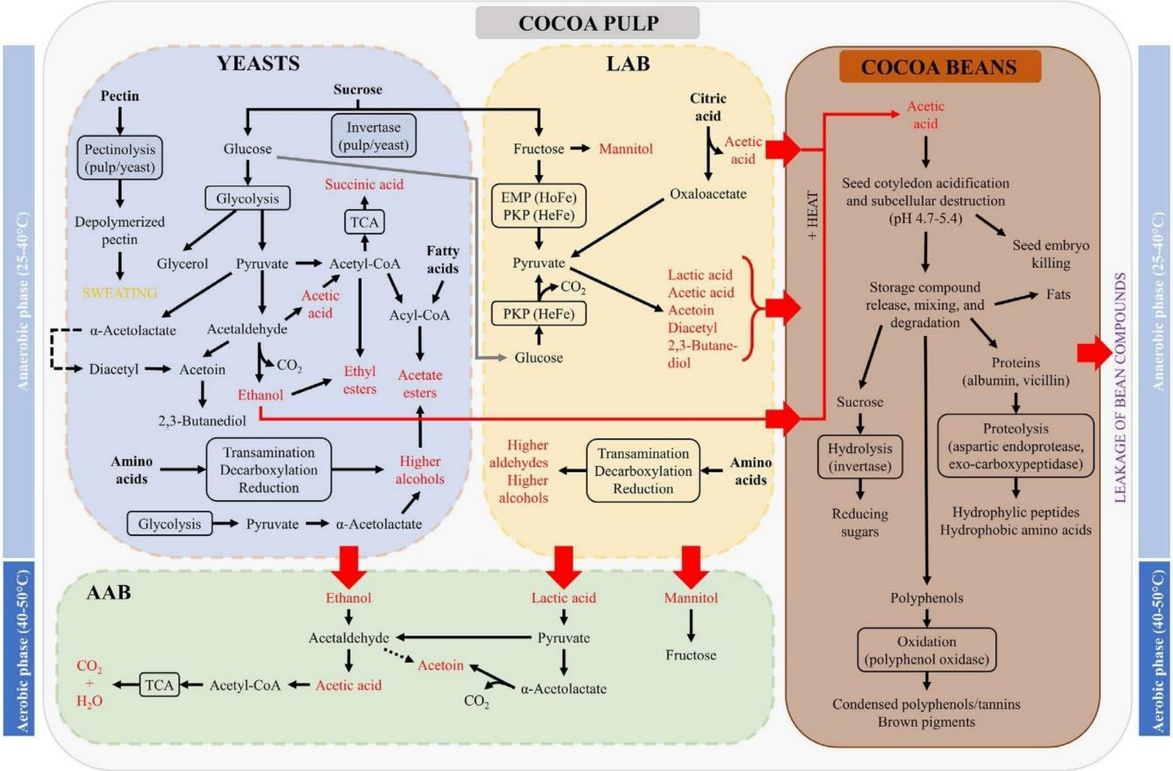

Figure 1. An overview of the microbial fermentation of the cocoa pulp-bean mass, including the succession of an anaerobic phase, involving yeasts and lactic acid bacteria and anaerobic phase, comprising acetic acid bacteria, and the concomitant bioconversion reactions within the cocoa beans. The figure does not represent the uptake of substrates and secretion of metabolites by the microbial cells. The abbreviations are as follows: Embden-Meyerhoff-Parnas pathway, EMP; Aspergillus -like HC deploy a heterofermentation, HeFe; Aspergillus -like HC deploy a homofermentation, HoFe; phosphoketolase pathway, PKP; tricarboxylic acid cycle, TCA (De Vuyst & Leroy, 2020)

Yeast in Fermentation:

The main fermentation yeast in inoculated fermentations is Saccharomyces cerevisiae due to its optimal fermentation capacity: it does extremely well to survive in high alcohol fermentation media, produces low volatile acidity and shows favourable aromatic results. Thus, winemakers perform inoculated fermentations by adding commercial active dry yeast preparations to the must, or alternatively, the indigenous yeast populations present in the vineyard or the winery environment carry out spontaneous fermentations (Chin et al., 2023). Yeast is responsible for alcoholic fermentation and thus determines the production of major alcohol and esters. The vast majority of wine yeasts are poor fermenters, are extremely sensitive to the increasing alcohol concentration, and hence, they either die shortly after initiation of the fermentation or are rapidly outperformed by Saccharomyces strains, the so-called “major” fermentative wine yeasts, which carry out ‘most of the fermentation and produce most of the wine alcohol (Mudoor Sooresh, Willing, & Bourrie, 2023). Alcoholic fermentation was achieved with natural microflora and the following wine yeast strains: Saccharomyces vini-Kakhuri 42 and Saccharomyces vini-Rkatsiteli 61. Yeast cells require oxygen to produce sterols, mainly ergosterol, and unsaturated fatty acids. Proportionally these components play extremely important role in the fluidity of the yeast cell membrane and for the activity of a variety of membrane-associated enzymes that influence ethanol tolerance, fermentative capacity, and the viability of the yeast (Watanabe, 2024). Very early studies on alcoholic fermentation have confirmed that:

1. As ethanol increases, most of Saccharomyces cerevisiae start the stationary phase and enter in a kind of dormancy.

2. The fermentation process is controlled only by S. cerevisiae, which eliminates all the non-Saccharomyces yeasts, which on their side is extremely sensitive to ethanol (Xia, Luo, Wu, & Zhang, 2023).

The unique fermentation properties and ability of Saccharomyces cerevisiae to shape flavor development and make it an important organism in fermentation processes for beer, wine and other alcoholic beverages. With the same strain, bananas or ale as well as sake and cider drinks can be made--just another reason they are centrally important across different alcoholic beverage industries (Krogerus & Gibson, 2020). It is not unusual for bread, dairy products, yogurt and wine to be mass-produced biotechnologically with these strains of yeast, notable for their fermentation skills. In beer fermentation, Saccharomyces cerevisiae has been employed since long before history was written down as a matter of course, with the yeast converting fermentable sugars in malted barley wort into ethanol and components of flavor (H. Elhalis, Cox, Frank, & Zhao, 2020). Moreover, strains of Saccharomyces cerevisiae isolated from vineyard environments demonstrate promise for lager beer production, underlining once more the adaptable and significant importance of this yeast species in brewing processes. The use of non-conventional Saccharomyces yeast strains, including interspecies hybrids, has led to exciting new areas of diversification for beer and has meant craft brewers can develop their own, distinct aroma profiles (Hu et al., 2022). Saccharomyces cerevisiae strains that allow anthocyanin-rich beer production from black wheat illustrate what role they play in fashioning fermented beverages that are not just novel but also nutritionally balanced (Bengoa, Iraporda, Garrote, & Abraham, 2019).

The impact of yeast on aroma structure and taste modulation in fermented drinks is a key aspect of the fermentation process. Yeasts take part in the generation of important aroma precursors through the actions of amino-acid metabolism so that ultimately, their final products such as chocolate become flavored and odorous with fruity hints (Semkiv et al., 2022). In wine production, yeast strains are the decisive factor in generating specific aroma profiles. Their crucial role can be illustrated by the very fact that wines have a smell and taste these days. Yeast help to make wine more aromatic type in liquid with lower concentration of substances such as esters, which contribute to aroma. The big yeast alpha-fetoproteins and flavour esters are the chief contributors to both flavour and aroma in fermented beverages, including beer (Kurylenko et al., 2021). They have a close bearing upon this final product's sensory qualities. Also, when fermenting mixed cultures of Saccharomyces cerevisiae and var. diastaticus fermented drinks, unique esters can arise that impact the taste profile of a drink. The selection of suitable yeast strains is not just for maximising alcohol yields, but also to maintain the sensory qualities of fermented drinks (Todorov et al., 2023).

Yeast metabolism is a paramount factor that determines the outcomes of fermentation, thus, influencing the quality and properties of the final product. The various factors associated with yeast metabolism include the glucose concentration, physicochemical composition, and microbial diversity associated with the response factors as they affect the fermentation process and the production of metabolites that influence the organoleptic properties of the final product (Bertacchi, Jayaprakash, Morrissey, & Branduardi, 2022). Studies have indicated that yeast metabolism is a reaction pathway that synthesizes various metabolites and by-products. The synthesis significantly influences the aroma formation and development in alcoholic beverage fermentation (Liang, Zhao, Curtis, & Gänzle, 2022). For instance, research concerning the impact of lipid mixtures on yeast metabolism has shown that its metabolism has a direct influence on fermentation performance and aroma formation. It has also been established that yeast strains, including Saccharomyces cerevisiae, influence the metabolic profile associated with aromatic and flavor production in wine fermentation (Devanthi et al., 2021). The investigation of yeast carbon partitioning revealed that yeast metabolism affects ethanol production and carbon dioxide synthesis. Yeast metabolic flux disparity associated with the yeast strains analyzed showed that ethanol production differed, with all the yeast strains generating e.g CO_2 at basal levels (Dzanaeva et al., 2020).

Microorganism involved in Fermentation:

Lactic acid bacteria are vital microorganisms in the fermentation of several foods that play a significant role in quality, flavor, and product maintenance. Used as starter cultures to ensure the achievement of particular technological properties, some strains have often been employed as adjunct cultures since they carry out distinctive metabolic functions that contribute to the development of taste, texture, and aroma (Kulkarni, Chethan, Srivastava, & Gabbur, 2022). They contain anti-inflammatory and immunomodulatory properties associated with their antioxidant properties and production of lactic acid, making their products valuable to the development of functional foods (Deed, Hou, Kinzurik, Gardner, & Fedrizzi, 2019). In dough fermentation, these can reduce the quality life of bread while increasing its aroma and taste through the production of organic acids. In the case of sausages-fermentation; some coagulase-negative staphylococci and yeast alongside LAB take part in metabolic fermentation, resulting in delicious products and those rich in nutrition. They are also known for their probiotic characteristics when consumed (Díaz-Muñoz & De Vuyst, 2022). Microorganisms are also associated with ensuring energetic feed quality following silage formation, with enhanced antioxidant content and anti-infective bacteria. They produce aromatic compounds, making it possible for the Chinese-style rice wine to benefit from them. Moreover, they acidify silage by converting water-soluble carbohydrates into organic acids, which prevent the development of harmful bacteria (Elghandour et al., 2020).

Malolactic fermentation is an essential process of winemaking that occurs after the alcoholic fermentation process and entails the deacidification of wine in terms of converting tough malic acid to soft lactic acid and CO_2, which in turn reduces the acidity of wine and makes it taste smoother (Dogan, Akman, & Tornuk, 2021). Malolactic fermentation is primarily performed by *Oenococcus oeni*, which is a nonpathogenic facultative anaerobic gram-positive lactic acid bacterium that has a high resistance to various stress factors during winemaking. The breakdown of malic acid by LAB during malolactic fermentation is achieved through decarboxylation, a slight increase in pH to obtain more microbial stability in wine, improved aroma due to enhanced complexity of the complex, and better wine (Soemarie, Milanda, & Barliana, 2021). Malolactic fermentation is essential for making red wine, as it tends to clear some of the sourness associated with malic acid and has additional benefits such as microbial stability and improved scent, among others. Malolactic fermentation can also be affected by the addition of malolactic-starter cultures meant to bring the acidity of wine to naturally reduce the wines and alterations of the ultimate product's organoleptic characteristics (W. H. Liu et al., 2023). The use of LAB strains like *Lactobacillus* plantarum during MLF can significantly alter the wine's chemical and sensorial characteristics as it modifies the organoleptic conferral of wine. Generally, while making wine during wine vinification, essential deacidification plays a vital role, which enhances the microbial stability and sensorial complexities, especially in red wines, being a central aspect of wine characteristics (Bouchez & De Vuyst, 2022).

Acetic acid bacteria are integral in the vinegar production process particularly through acetic acid fermentation. In vinegar fermentation process, Acetic acid bacteria including *Acetobacter aceti* and *Gluconobacter* occupy as the principal bacteria that are widely present in the vinegar factory, where they initiate the fermentation of acetic stock converting alcohol to acetic acid via the aldehyde intermediary (Dudley & Maro, 2021). These viable obligate aerobic Gram-negative bacteria with the potential for ethanol oxidation, acetic acid synthesis, and acid endurance are the type of bacteria that are naturally occurring in the vinegar, and the associated taste and smell from these bacteria's activity in vinegar production are associated with the acetic acid and the rest of the fermented products that are simultaneously being produced. The saccharomyces cerevisiae and acetic acid bacteria microbial consortium that transmuted the carbohydrate to acetic acid, makes the vinegar high in acetic acid while it dissipated the alcohol into acetic acid (L. Feng, Gu, Guo, Mu, & Tuo, 2023). The salient species of acetic acid bacteria for the production of vinegar are *Acetobacter aceti* and *Komagataeibacter* europaeus where these bacteria help in the production of vinegar from numerous sources and raw materials in free or immobilized culture (Tofalo et al., 2020). Also, these bacteria participate in the production of vinegar from fruits like mangos and papaya, once again imparting flavor and health benefit. Acetic acid fermentation activity by acetic acid bacteria is vital to the deacidification, biologic certitude, and olfactory potence established as congenital element in the vinegar manufacturing process (Fukami et al., 2021).

Interactions Between Bacteria and Yeast:

The interaction between bacteria and yeast in the fermentation process may indicate both synergism and antagonism between these microorganisms that ultimately determine the outcomes and peculiarities of the final products. Thus, lactic acid bacteria and yeast in sourdough fermentation demonstrate a synergistic relationship because of the ability of LAB to ferment malt sugars while yeast, living on the by-products, produce carbon dioxide and ethanol that makes the dough rise and gives it a sour taste (Al Daccache et al., 2020). Competition is the example of antagonism that may occur during fermentation, such as the competition between different yeasts in wine fermentation. Such antagonism negatively affects the overall fermentation process and the quality of the final product basing on the example of the increased acetic acid production (Bourdichon et al., 2021).

For example, the fermentation of green coffee kombucha entailed the symbiotic interaction of acetic acid bacteria of the family and osmophilic yeast, which promoted the formation of fermentation products with improved anti-radical and anti-aging characteristics. The whole microbial composition comprising the symbiotic culture of bacteria and yeast in kombucha fermentation develops a favorable habitat, where the embedded microorganisms receive oxygen and the necessary nutrients, thereby demonstrating a mutualistic action (Cera et al., 2024). For one, there could be competition between several species of yeast in wine fermentation, which could directly impact the activity of fermentation as well as the quality of the end product. The microbial dynamics of spontaneous fermentation during the fermentation of cocoa beans occur in such a way that succession of yeasts followed by lactic acid bacteria and Bacillus species are Phyla that yield the fermentation stages of the cocoa beans which impacts the quality of the beans (Rocha, Kovacevik, Veličkovska, Tamame, & Teixeira, 2023). Yeasts are important in pulp breakdown during cocoa fermentation. Yeasts also allow air to percolate into the fermenting mass in the whole fermentation process. In the development of sour beer, pre-fermentation with lactic acid bacteria can provide a thrilling experience and a great taste to beer during the fermentation process (Ashaolu, Khalifa, Mesak, Lorenzo, & Farag, 2023).

The importance of microbial interaction for the fermentation process cannot be overemphasized. It is noted that microbial interactions have a high impact on fermentation processes, shaping the quality, flavor, and specific characteristics of the final product (Y. Liu et al., 2020). For instance, in fermentation of green coffee kombucha, the synergy of acetic acid bacteria and osmophilic yeast may produce fermentation products possessing better antioxidant and anti-aging properties through their interaction. Meanwhile, learning more about the microbial dynamics of uncontrolled fermentation as in the case of fermentation of Gayo Arabica wine coffee, where yeasts interact with bacteria may affect the duration of fermentation stages and final product quality. Interactions between yeast and lactic acid bacteria contribute to the variation of wine phenolic composition through both direct and indirect effect, such as cell-wall adsorption or direct enzyme activities and metabolite, fermentation products production, respectively (Wang, Yang, Wei, Qiao, & Chen, 2022). Likewise, the interaction between yeast and lactic acid bacteria in sour beer fermentation helps to speed up the fermentation process, enhancing the taste of the beer (Tu et al., 2022).

Applications of Fermentation in Food and Beverage Production:

Newly synthesized products from fermentation, including cheese, yogurt, and sauerkraut, among others, have various flavors and textures. Cheese is produced through acidification, coagulation, and the development of flavors formed by lactic acid bacteria through the fermentation process. Acidification results from lactic acid bacteria's activity when they convert citrate and other milk sugars into lactic acid (Assad, Ashaolu, Khalifa, Baky, & Farag, 2023). On the other hand, yogurt fermentation is yielded when milk forms a gelatinous texture from adding bacterial strains like *L. bulgaricus* and *S. thermophiles*. *Lactobacillus* bulgaricus creates a creamy texture with a tart flavor once detected in the mouth while *S. thermophiles* ferments other sugars to supply flavor and other nutrients (Zhao, Kokawa, Amini, Dong, & Kitamura, 2023).

The other fermented food, sauerkraut, is mainly produced through lactic acid fermentation and end-products by Lactic Acid Bacteria, while this process involves converting sugars from cabbage to acid by LAB. The fermentation product includes a sour taste with all the nutritional benefits of the cabbage preserved in an inert toper layer. Apart from being enjoyable in sensory properties, the resultant products from fermentation have been studied to produce more benefits due to their exposure to probiotic microorganisms and bioactive compounds as shown earlier. Due to metabolic traits of lactic acid bacteria observed earlier, these bacteria have extensively been used in the food sector (Ogawa, Bisson, García-Martínez, Mauricio, & Moreno-García, 2019). Moreover, Fermented foods have been studied extensively to determine the population of the microbes and their insights, including diversity and health beneficial properties. This study also looked into Lightly Fermented Vegetables to illustrate the meaning of using fermentation facts in technology (O'Toole D, 2019).

Fruits and Vegetables Presented as fermentation examples in this work are indicative of the products made based on understandings from fermentation studies. Given the above information, this research illustrated the application of Lactobacilli in the production of various foods such as cheese, olives, Lavash, rye bread, and vegetables. The application of fermentation products and their sources in various foods, beverages, and other edibles across continents also showed their beneficial method to the environment and the users (Ejaz & Sohail, 2021).

The brewing process of alcoholic beverages, such as beer and wine, is a complicated interaction of microorganisms that ultimately affect the product. Beer brewing primarily involves the microbiology of malting and fermentation, which are vital in determining the flavor and aroma of the beer. The primary microorganism in the fermentation process is yeast, particularly Saccharomyces cerevisiae, that metabolize sugar into alcohol while produces different flavor components (Kessi-Pérez, Molinet, & Martínez, 2020). Additionally, lactic acid bacteria are responsible for the fermentation process in some beer styles that contribute to flavors. Wine is made by the fermentation of grape juice by fermentation by yeast, primarily Saccharomyces cerevisiae. Lactic acid bacteria primarily ferment malic acid in a process called malolactic fermentation which is their contribution to the flavor in wines (Griggs, Steenwerth, Mills, Cantu, & Bokulich, 2021).

Understanding brewing microbiology is critical to maintain sensory quality in the end product of beer and wine. Brewing is mainly influenced by the water mineral composition, beer production method, and the type of yeast used that affect the end product in terms of the antioxidant capacity, color, and flavor (Gobert, Tourdot-Maréchal, Sparrow, Morge, & Alexandre, 2019). The cold brew coffee production process involves roasting, extraction methods, flavor development, and food safety precautions which should be moderated for product quality. The brewing process reduces aflatoxins in traditional African beverages and promotes anthocyanin beer production showing health benefits of the same (Ghosh, Bornman, Meskini, & Joghataei, 2023).

Bacteria and yeast that initiate and propel the fermentation of various food products, e.g. soy sauce, kombucha, and other fermented foods, play an essential role during this process. In kombucha, a community of bacteria and yeast ferments the fermentation of a start tea, such as black or green tea with the addition of sugar. This is after covered with a biofilm that forms over several weeks and comprises microorganisms that work together, e.g. the yeasts and the acetic acid bacteria responsible for the vinegary taste of the kombucha (Tian et al., 2021). This process results in the creation of a daughter SCOBY, a disc-shaped gelatinous pellicle, which forms with the development of fermentation and the utilization of the liquid phase’s compositions through the symbiotic bacteria starter and yeast. The fermentation of fruits and herbs raw materials with a symbiotic culture of bacteria and yeast allows for the production of ferments rich in diversified compounds with several valuable properties, such as a beneficial effect and increased division and activity of skin cells (Porter, Divol, & Setati, 2019). The reduced pH of kombucha samples after fermentation is a result of the increased acetic acid and other organic acids produced through the fermentation of the liquid by bacteria and yeast present in the kombucha culture (Ganapathiwar, Pappula, Banothu, & Bhukya, 2023).

Health Benefits and Nutritional Aspects:

The bioactive compounds produced during fermentation add to the overall nutritional value and health functionality of the fermented products. Important to note is that fermentation leads can enhance the increase in vital nutrients such as vitamins, minerals, and antioxidants and thus contribute to high nutrient enrichment in the products (Bartle et al., 2021). Fibers in fermented foods and beverages release the bioactive compounds and the smaller molecules are metabolized and absorbed at the intestinal levels translating to health promotion (de la Cerda Garcia-Caro et al., 2022).

Fermenting soy milk using different types of lactic acid bacteria exhibited antioxidative activities partially due to bioactive components such as peptides, isoflavones, and phenolic compounds produced during fermentation. It is also vital to note that there are higher SCFAs levels in fermented foods and beverages than in their non-fermented counterparts (Lopez, Rocchetti, Fontana, Lucini, & Rebecchi, 2022). This show the role microorganisms play in metabolizing the food matrices and in producing bioactive substances. Various studies have shown fermented foods and beverages have positively impacted human health. Proto-correlation mechanisms have been proposed to include fermentation because; fermented foods are directly nutritious; provision of nutrients supports growth of the gut microbes and its microbiome and that the fermenting microbes can survive past gastric juices when ingested (Rastogi et al., 2022).

The bioactive features of the functional fermented foods can be achieved through two correlation approaches; direct correlation with the live microbes in the foods or through correlation with the live microbe's metabolites and products bioactive aspect (Perpetuini, Prete, Garcia-Gonzalez, Khairul Alam, & Corsetti, 2020). Fermented foods are foods produced using the works of microorganisms and therefore under enzymatic-like conversions enhanced to be resistance to decomposition and also in activity and prolonging the products' nutritional and therapeutic lifespan. Foods and beverages fermentation can also lead to the production of bioactive compounds like phenolics, flavonoids, and bio-peptides with antioxidative activities and inhibitory properties to food pathogens (Richter et al., 2022).

Fermented dairy products pose as potential matrices for functional food production due to the incorporation of bioactive extracts and ingredients. Foods and beverages fermentation can also lead to the production of bioactive products like organic acids and bacteriocins with various correlation biological activity. Fermented products have also been beneficial to human health due to the functionality and provision of essential foods, proteins, vitamins, and other composite feeding and nutrients with functional and nutritional values (Barbosa, Ramalhosa, Vasconcelos, Reis, & Mendes-Ferreira, 2022). Important concepts note with the fermentation process is that it leads to the release of secondary bioactive compounds from natural occurrences and the creation of new bioactive products. Fermentation processes lead to the release of important secondary compounds from nature and the production of new important essential and bioactive components due to biofunctional factors. The functional similarity responsible for releasing bioactive products from natural occurrences and forming new bioactive ferment beads (Teleky, Martău, Ranga, Cheţan, & Vodnar, 2020).

The probiotic properties of fermented foods have become a major area of interest, and studies have revealed the potential benefits of these foods not only on health but the society as well. Today, more people are turning to foods such as yogurt, fermented oats, and other products rich in various probiotic strains (Binati et al., 2021). Such foods are described as probiotic fermented foods and are intended to encourage gut health through regular consumption. Over the years, fermented dairy foods such as yogurt have been commonly used to deliver probiotic strains because they offer the right conditions under which the strains can thrive and enhance human health (Alfonzo, Sicard, Di Miceli, Guezenec, & Settanni, 2021).

The potential of yeasts in various traditional fermented foods and beverages has been studied in the recent past, and their functional role has been revealed in improving gut health. Fermented foods have been the most efficient carriers of probiotic bacteria as these foods and the metabolites produced during fermentation have enhanced the probiotic nature of specific strains (Hu et al., 2021). The integration of probiotic starters in food fermentation has been used to modify the food for sensory and health benefits, which have made most people utilize their functionalities. Probiotics enhance the nutritional value and health benefits of baked goods by promoting gut health and boosting the immune system. They also improve the texture and flavor, while potentially extending the shelf life of the products. Several studies have concluded that fermented foods are the best probiotics for every individual because it is a source of delicious food that not only improves gut health but the general wellness of the consumers (Pater, Satora, Zdaniewicz, & Sroka, 2022).

Fermentation actively affects the achievement of improved nutritional parameters and health outcomes of foods. This is also due to production of various probiotics and bioactive compounds. As evidenced in the findings of the studies, fermented vegetable products are considered more pro-health thanks to probiotic properties and the content of more vitamin C (Procópio et al., 2022). Furthermore, it is associated with the ability to increase human immunity. Thus, such fermented products such as yogurt, kefir, kombucha, some cheeses, sausages, and pickles are considered probiotic, which ensures proper digestion and health of the individual. Embedding fruits by-products to probiotic-fermented food is relevant as they may shield the probiotics from harsh exposure (Vicente et al., 2021).

Future Directions and Research Prospects:

Fermentation research likely continues to reveal many other ways to approach and apply this pillar of food technology. On the basis of the reviewed works, such modern trends in fermentation studies can be outlined. J. Zhang, Fang, Huang, Ding, and Wang (2022) carried a research work on the evolution of polyphenolic, anthocyanin, and organic acid components in blueberry wine during co-inoculation fermentation. Versari et al. (2015) investigated chemical and sensory changes in commercial Cabernet Franc red wine from Switzerland during co-inoculation with yeast and bacteria. Yu et al. (2020) analyzed the effects of various probiotic combinations on the content and bioactivity of Spirulina. Fermentation research could propagate other working ideas to advance the metabolism under their direction of various food matrices.

Several studies have been done to explore bacteria and yeast's novel fermentation processes which can be tapped to improve various types of fermentation products. For example, Adler et al. (2014) investigated the metabolic fluxes of acetic acid bacteria during cocoa pulp fermentation. On the other hand, Vuyst and Weckx (2016) documented microbial activities occurring during cocoa bean fermentation. Maicas and Mateo (2016) also conducted a research on microbial glycosidase applications for obtaining wine and tabulate a wide application of yeast strains which produced various flavors during fermentation. Lastly, Dippel et al. (2022) have researched on co-fermentation of Kveik and non-conventional yeast for aroma modulation where a variety of aromas can be modulated during the fermentation process. These examples showed the varieties of how bacteria and yeast can be used in novel fermentation processes to improve product quality and generate diverse flavor compounds.

Areas that might be ripe for further investigation or be improved by new breakthroughs take in fermentation. Therefore, new technological carries gain large slack by any suitable lice of thought, as in the case of biotechnology technicians and researchers who transformed microbes into the primary purifiers for many water-polluted places left untouched after connection with humans using a pulsed electric field device for cleaning off pollutants from water. With digital and nano-technology at the forefront as another promising option is fermentation systems employing computational approaches to simulate biological processes in true mimicry of nature. Studies like Mukherjee, Gómez-Sala, O'Connor, Kenny, and Cotter (2022), which examines the international regulatory structures for fermented foods and beverages produced using traditional methods; or Yang, Fan, and Xu (2020) insight into meta proteomics studies of food substrates that are part and parcel of common dietary habits around the world provide insight about the legal aspects and proteomic analysis of fermentative products.

Additionally, work done by Haile and Kang (2019) about microorganisms' function in coffee fermentation and Li, Gao, Zhang, Guo, and Bao-cheng (2022) on anearobic solid-state fermentation with *Bacillus subtilis* for hydrolizing free gossypol which emphasizes the role of microbial activities as well as fermentation quality. Potential fields of study for the future could include how to make use of emerging methods such as pulsed electric field in wine fermentation examined by Y. Feng et al. (2022) and the nitrogen status and fermentation performance of non-Saccharomyces yeasts as for instance. These combined developments have stimulated renewed interest in R&D concerning fermentation foods especially traditional fermented foods, so science seeks to make use of this information to develop new products and ingredients with a suitable fermented taste that will be marketed.

Conclusion:

Bacteria and yeast also control the characteristics and qualities of other end products from fermentation processes. For instance, lactic acid bacteria are essential in fermenting drinks as wine and soy sauce due to their role in improving the functional properties and flavor improvements in the products (Motlhanka, Lebani, Boekhout, & Zhou, 2020). Yeast is directly linked to fermentation as the microbe influences the flavor and taste in ese traditional liquor and coffee beans. The symbiotic culture of bacteria and yeast in kombucha facilitates the production of a biofilm that initiates the fermentation process while enhancing the distinct taste in the end product (Hosam Elhalis, Cox, & Zhao, 2023). Other factors affecting drink-related fermentation include the dynamics of microbes in spontaneous fermentation of cocoa beans. Yeast, lactic acid bacteria, and acetic acid bacteria govern the flavors and qualities of cocoa end products during fermentation. Generally, bacteria and yeast work towards producing fermented foods and drinks from which unique characteristics are gained depending on the production process (Ngangue et al., 2022).

To optimize fermentation processes, it is imperative that microbial interactions be understood. These interactions significantly determine the dynamics and outcomes of fermentation. By shaping the fermentation environment, interactions between microorganisms (e.g., bacteria and yeast) greatly affect several different kinds of food products and drinks. H. Zhang, Tan, Wei, Du, and Xu (2022) and An et al. (2023) stressed this point in their studies on the importance of understanding microbial interaction in soybean-based fermented foods as well as solid-state fermentation systems to help design better fermentations for improved food products.

Deka et al. (2021) have further emphasized the importance of discovery for optimal fermentation of certain plant products by combining members of a synthetic microbial consortia with food components and correlating this information with microbial populations. More in-depth research, like that carried out by Soltan and Patra (2022) and White et al. (2022), looks at how phages also take part in regulating microbial composition during lactose fermentations; these studies contain new evidence regarding phage impacts on microbial numbers and diversity. This knowledge serves to suggest microbial interactions as the focal point for enhancements to fermentation processes and products.

Fermentation research has many implications for various industries and health- based outcomes. Potential applications range from food production to biofuel development. For example, production of gluconic acid and its derivatives by microbial fermentation -- as covered in studies such as that by Ma, Li, Zhang, Wang, and Chen (2022) -- signal progress in improving fermentation processes for industrial applications. Work by Kadar, Astawan, Putri, and Fukusaki (2020) on metabolomics- based research into fermentation at the larger product volume, provides a model for keeping quality controls on target at scale. Along these lines, studies such as those by Shi et al. (2022) on the multi-omics analysis of fermented foods and drinks, as well as work from Majchrzak, Motyl, and Śmigielski (2022) regarding the cosmetic implications of fermented raw materials of biological origin, suggest that there potentially can be developed healthy and functional products by fermentation courses.

. References

Adler, P., Frey, L. J., Berger, A., Bolten, C. J., Hansen, C. E., & Wittmann, C. (2014). The Key to Acetate: Metabolic Fluxes of Acetic Acid Bacteria Under Cocoa Pulp Fermentation-Simulating Conditions. Applied and Environmental Microbiology, 80(15), 4702-4716. doi: 10.1128/aem.01048-14

Al Daccache, M., Koubaa, M., Maroun, R. G., Salameh, D., Louka, N., & Vorobiev, E. (2020). Impact of the Physicochemical Composition and Microbial Diversity in Apple Juice Fermentation Process: A Review. Molecules, 25(16). doi: 10.3390/molecules25163698

Alfonzo, A., Sicard, D., Di Miceli, G., Guezenec, S., & Settanni, L. (2021). Ecology of yeasts associated with kernels of several durum wheat genotypes and their role in co-culture with Saccharomyces cerevisiae during dough leavening. Food Microbiol, 94, 103666. doi: 10.1016/j.fm.2020.103666

An, F., Wu, J., Feng, Y., Pan, G., Ma, Y., Jiang, J., . . . Zhao, M. (2023). A Systematic Review on the Flavor of Soy-based Fermented Foods: Core Fermentation Microbiome, Multisensory Flavor Substances, Key Enzymes, and

Metabolic Pathways. Comprehensive Reviews in Food Science and Food Safety, 22(4), 2773-2801. doi: 10.1111/1541-4337.13162

Ashaolu, T. J., Khalifa, I., Mesak, M. A., Lorenzo, J. M., & Farag, M. A. (2023). A comprehensive review of the role of microorganisms on texture change, flavor and biogenic amines formation in fermented meat with their action mechanisms and safety. Crit Rev Food Sci Nutr, 63(19), 3538-3555. doi: 10.1080/10408398.2021.1929059

Assad, M., Ashaolu, T. J., Khalifa, I., Baky, M. H., & Farag, M. A. (2023). Dissecting the role of microorganisms in tea production of different fermentation levels: a multifaceted review of their action mechanisms, quality attributes and future perspectives. World J Microbiol Biotechnol, 39(10), 265. doi: 10.1007/s11274-023-03701-5

Barbosa, C., Ramalhosa, E., Vasconcelos, I., Reis, M., & Mendes-Ferreira, A. (2022). Machine Learning Techniques Disclose the Combined Effect of Fermentation Conditions on Yeast Mixed-Culture Dynamics and Wine Quality. Microorganisms, 10(1). doi: 10.3390/microorganisms10010107

Bartle, L., Peltier, E., Sundstrom, J. F., Sumby, K., Mitchell, J. G., Jiranek, V., & Marullo, P. (2021). QTL mapping: an innovative method for investigating the genetic determinism of yeast-bacteria interactions in wine. Appl Microbiol Biotechnol, 105(12), 5053-5066. doi: 10.1007/s00253-021-11376-x

Bayoumy, A. B., Mulder, C. J. J., Mol, J. J., & Tushuizen, M. E. (2021). Gut fermentation syndrome: A systematic review of case reports. United European Gastroenterol J, 9(3), 332-342. doi: 10.1002/ueg2.12062

Bengoa, A. A., Iraporda, C., Garrote, G. L., & Abraham, A. G. (2019). Kefir micro-organisms: their role in grain assembly and health properties of fermented milk. J Appl Microbiol, 126(3), 686-700. doi: 10.1111/jam.14107

Bertacchi, S., Jayaprakash, P., Morrissey, J. P., & Branduardi, P. (2022). Interdependence between lignocellulosic biomasses, enzymatic hydrolysis and yeast cell factories in biorefineries. Microb Biotechnol, 15(3), 985-995. doi: 10.1111/1751-7915.13886

Binati, R. L., Salvetti, E., Bzducha-Wróbel, A., Bašinskienė, L., Čižeikienė, D., Bolzonella, D., & Felis, G. E. (2021). Non-conventional yeasts for food and additives production in a circular economy perspective. FEMS Yeast Res, 21(7). doi: 10.1093/femsyr/foab052

Bouchez, A., & De Vuyst, L. (2022). Acetic Acid Bacteria in Sour Beer Production: Friend or Foe? Front Microbiol, 13, 957167. doi: 10.3389/fmicb.2022.957167

Bourdichon, F., Arias, E., Babuchowski, A., Bückle, A., Bello, F. D., Dubois, A., . . . Morelli, L. (2021). The forgotten role of food cultures. FEMS Microbiol Lett, 368(14). doi: 10.1093/femsle/fnab085

Cera, S., Tuccillo, F., Knaapila, A., Sim, F., Manngård, J., Niklander, K., . . . Coda, R. (2024). Role of tailored sourdough fermentation in the flavor of wholegrain-oat bread. Curr Res Food Sci, 8, 100697. doi: 10.1016/j.crfs.2024.100697

Chin, X. H., Ho, S., Chan, G., Basri, N., Teo, M., Thong, A., . . . Peterson, E. C. (2023). Aromatic Yeasts: Interactions and Implications in Coffee Fermentation Aroma Profiles. J Agric Food Chem, 71(25), 9677-9686. doi: 10.1021/acs.jafc.3c01357

Comitini, F., Agarbati, A., Canonico, L., & Ciani, M. (2021). Yeast Interactions and Molecular Mechanisms in Wine Fermentation: A Comprehensive Review. Int J Mol Sci, 22(14). doi: 10.3390/ijms22147754

Coral-Medina, A., Fenton, D. A., Varela, J., Baranov, P. V., Camarasa, C., & Morrissey, J. P. (2022). The evolution and role of the periplasmic asparaginase Asp3 in yeast. FEMS Yeast Res, 22(1). doi: 10.1093/femsyr/foac044

Cuevas-González, P. F., González-Córdova, A. F., Vallejo-Cordoba, B., Aguilar-Toalá, J. E., Hall, F. G., Urbizo-Reyes, U. C., . . . García, H. S. (2022). Protective role of lactic acid bacteria and yeasts as dietary carcinogen-binding agents - a review. Crit Rev Food Sci Nutr, 62(1), 160-180. doi: 10.1080/10408398.2020.1813685

de la Cerda Garcia-Caro, R., Hokamp, K., Roche, F., Thompson, G., Timouma, S., Delneri, D., & Bond, U. (2022). Aneuploidy influences the gene expression profiles in Saccharomyces pastorianus group I and II strains during fermentation. PLoS Genet, 18(4), e1010149. doi: 10.1371/journal.pgen.1010149

De Vuyst, L., & Leroy, F. (2020). Functional role of yeasts, lactic acid bacteria and acetic acid bacteria in cocoa fermentation processes. FEMS Microbiol Rev, 44(4), 432-453. doi: 10.1093/femsre/fuaa014

Deed, R. C., Hou, R., Kinzurik, M. I., Gardner, R. C., & Fedrizzi, B. (2019). The role of yeast ARO8, ARO9 and ARO10 genes in the biosynthesis of 3-(methylthio)-1-propanol from L-methionine during fermentation in synthetic grape medium. FEMS Yeast Res, 19(2). doi: 10.1093/femsyr/foy109

Deka, P., Mehetre, G. T., Lalnunmawii, E., Upadhyaya, K., Singh, G., Hashem, A., . . . Abd_Allah, E. F. (2021). Metagenomic Analysis of Bacterial Diversity in Traditional Fermented Foods Reveals Food-Specific Dominance of Specific Bacterial Taxa. Fermentation, 7(3), 167. doi: 10.3390/fermentation7030167

Devanthi, P. V. P., Kho, K., Nurdiansyah, R., Briot, A., Taherzadeh, M. J., & Aslanzadeh, S. (2021). Do Kombucha Symbiotic Cultures of Bacteria and Yeast Affect Bacterial Cellulose Yield in Molasses? J Fungi (Basel), 7(9). doi: 10.3390/jof7090705

Díaz-Muñoz, C., & De Vuyst, L. (2022). Functional yeast starter cultures for cocoa fermentation. J Appl Microbiol, 133(1), 39-66. doi: 10.1111/jam.15312

Dippel, K., Matti, K., Muno-Bender, J., Michling, F., Brezina, S., Semmler, H., . . . Wendland, J. (2022). Co-Fermentations of Kveik With Non-Conventional Yeasts for Targeted Aroma Modulation. Microorganisms, 10(10), 1922. doi: 10.3390/microorganisms10101922

Dogan, K., Akman, P. K., & Tornuk, F. (2021). Role of non-thermal treatments and fermentation with probiotic Lactobacillus plantarum on in vitro bioaccessibility of bioactives from vegetable juice. J Sci Food Agric, 101(11), 4779-4788. doi: 10.1002/jsfa.11124

Dudley, R., & Maro, A. (2021). Human Evolution and Dietary Ethanol. Nutrients, 13(7). doi: 10.3390/nu13072419

Dzanaeva, L., Kruk, B., Ruchala, J., Nielsen, J., Sibirny, A., & Dmytruk, K. (2020). The role of peroxisomes in xylose alcoholic fermentation in the engineered Saccharomyces cerevisiae. Cell Biol Int, 44(8), 1606-1615. doi: 10.1002/cbin.11353

Ejaz, U., & Sohail, M. (2021). Supporting role of lignin in immobilization of yeast on sugarcane bagasse for continuous pectinase production. J Sci Food Agric, 101(4), 1709-1714. doi: 10.1002/jsfa.10764

Elghandour, M. M. Y., Khusro, A., Adegbeye, M. J., Tan, Z., Abu Hafsa, S. H., Greiner, R., . . . Salem, A. Z. M. (2020). Dynamic role of single-celled fungi in ruminal microbial ecology and activities. J Appl Microbiol, 128(4), 950-965. doi: 10.1111/jam.14427

Elhalis, H., Cox, J., Frank, D., & Zhao, J. (2020). The crucial role of yeasts in the wet fermentation of coffee beans and quality. Int J Food Microbiol, 333, 108796. doi: 10.1016/j.ijfoodmicro.2020.108796

Elhalis, H., Cox, J., & Zhao, J. (2023). Yeasts Are Essential for Mucilage Degradation of Coffee Beans During Wet Fermentation. Yeast, 40(9), 425-436. doi: 10.1002/yea.3888

Fatima, R. (2023). Potential of Gut Microbiome in mosquitoes for Dengue Vector Control. *Journal of Islamabad Medical & Dental College*, *12*(3), 214-221.

Feng, L., Gu, J., Guo, L., Mu, G., & Tuo, Y. (2023). Safety evaluation and application of lactic acid bacteria and yeast strains isolated from Sichuan broad bean paste. Food Sci Nutr, 11(2), 940-952. doi: 10.1002/fsn3.3129

Feng, Y., Yang, T., Zhang, Y., Zhang, A., Gai, L., & Niu, D. (2022). Potential Applications of Pulsed Electric Field in the Fermented Wine Industry. Frontiers in Nutrition, 9. doi: 10.3389/fnut.2022.1048632

Fukami, H., Higa, Y., Hisano, T., Asano, K., Hirata, T., & Nishibe, S. (2021). A Review of Red Yeast Rice, a Traditional Fermented Food in Japan and East Asia: Its Characteristic Ingredients and Application in the Maintenance and Improvement of Health in Lipid Metabolism and the Circulatory System. Molecules, 26(6). doi: 10.3390/molecules26061619

Ganapathiwar, S., Pappula, R., Banothu, A. K., & Bhukya, B. (2023). Causatum of Probiotic Yeast Saccharomyces cerevisiae SBO1 Supplementation on Growth and Aflatoxin Amelioration in Broilers. Indian J Microbiol, 63(3), 253-262. doi: 10.1007/s12088-023-01078-5

Ghosh, S., Bornman, C., Meskini, M., & Joghataei, M. (2023). Microbial Diversity in African Foods and Beverages: A Systematic Assessment. Curr Microbiol, 81(1), 19. doi: 10.1007/s00284-023-03481-z

Gobert, A., Tourdot-Maréchal, R., Sparrow, C., Morge, C., & Alexandre, H. (2019). Influence of nitrogen status in wine alcoholic fermentation. Food Microbiol, 83, 71-85. doi: 10.1016/j.fm.2019.04.008

Griggs, R. G., Steenwerth, K. L., Mills, D. A., Cantu, D., & Bokulich, N. A. (2021). Sources and Assembly of Microbial Communities in Vineyards as a Functional Component of Winegrowing. Front Microbiol, 12, 673810. doi: 10.3389/fmicb.2021.673810

Haile, M., & Kang, W. H. (2019). The Role of Microbes in Coffee Fermentation and Their Impact on Coffee Quality. Journal of Food Quality, 2019, 1-6. doi: 10.1155/2019/4836709

Hu, Y., Yang, Q., Chen, D., Fu, B., Zhang, Y., Zhang, Y., . . . Zhao, S. (2021). Study on microbial communities and higher alcohol formations in the fermentation of Chinese Xiaoqu Baijiu produced by traditional and new mechanical technologies. Food Res Int, 140, 109876. doi: 10.1016/j.foodres.2020.109876

Hu, Y., Zhang, J., Wang, S., Liu, Y., Li, L., & Gao, M. (2022). Lactic acid bacteria synergistic fermentation affects the flavor and texture of bread. J Food Sci, 87(4), 1823-1836. doi: 10.1111/1750-3841.16082

Kadar, A. D., Astawan, M., Putri, S. P., & Fukusaki, E. (2020). Metabolomics-Based Study of the Effect of Raw Materials to the End Product of Tempe—An Indonesian Fermented Soybean. Metabolites, 10(9), 367. doi: 10.3390/metabo10090367

Kessi-Pérez, E. I., Molinet, J., & Martínez, C. (2020). Disentangling the genetic bases of Saccharomyces cerevisiae nitrogen consumption and adaptation to low nitrogen environments in wine fermentation. Biol Res, 53(1), 2. doi: 10.1186/s40659-019-0270-3

Krogerus, K., & Gibson, B. (2020). A re-evaluation of diastatic Saccharomyces cerevisiae strains and their role in brewing. Appl Microbiol Biotechnol, 104(9), 3745-3756. doi: 10.1007/s00253-020-10531-0

Kulkarni, N. A., Chethan, H. S., Srivastava, R., & Gabbur, A. B. (2022). Role of probiotics in ruminant nutrition as natural modulators of health and productivity of animals in tropical countries: an overview. Trop Anim Health Prod, 54(2), 110. doi: 10.1007/s11250-022-03112-y

Kurylenko, O., Ruchala, J., Kruk, B., Vasylyshyn, R., Szczepaniak, J., Dmytruk, K., & Sibirny, A. (2021). The role of Mig1, Mig2, Tup1 and Hap4 transcription factors in regulation of xylose and glucose fermentation in the thermotolerant yeast Ogataea polymorpha. FEMS Yeast Res, 21(4). doi: 10.1093/femsyr/foab029

Li, J., Gao, T., Zhang, H., Guo, X., & Bao-cheng, Z. (2022). Anaerobic Solid-State Fermentation With Bacillus Subtilis for Digesting Free Gossypol and Improving Nutritional Quality in Cottonseed Meal. Frontiers in Nutrition, 9. doi: 10.3389/fnut.2022.1017637

Liang, N., Zhao, Z., Curtis, J. M., & Gänzle, M. G. (2022). Antifungal cultures and metabolites of lactic acid bacteria for use in dairy fermentations. Int J Food Microbiol, 383, 109938. doi: 10.1016/j.ijfoodmicro.2022.109938

Liu, W. H., Chai, L. J., Wang, H. M., Lu, Z. M., Zhang, X. J., Xiao, C., . . . Xu, Z. H. (2023). Bacteria and filamentous fungi running a relay race in Daqu fermentation enable macromolecular degradation and flavor substance formation. Int J Food Microbiol, 390, 110118. doi: 10.1016/j.ijfoodmicro.2023.110118

Liu, Y., Wan, Z., Yohannes, K. W., Yu, Q., Yang, Z., Li, H., . . . Wang, J. (2020). Functional Characteristics of Lactobacillus and Yeast Single Starter Cultures in the Ripening Process of Dry Fermented Sausage. Front Microbiol, 11, 611260. doi: 10.3389/fmicb.2020.611260

Lopez, C. M., Rocchetti, G., Fontana, A., Lucini, L., & Rebecchi, A. (2022). Metabolomics and gene-metabolite networks reveal the potential of Leuconostoc and Weissella strains as starter cultures in the manufacturing of bread without baker's yeast. Food Res Int, 162(Pt A), 112023. doi: 10.1016/j.foodres.2022.112023

Ma, Y., Li, B., Zhang, X., Wang, C., & Chen, W. (2022). Production of Gluconic Acid and Its Derivatives by Microbial Fermentation: Process Improvement Based on Integrated Routes. Frontiers in Bioengineering and Biotechnology, 10. doi: 10.3389/fbioe.2022.864787

Maicas, S., & Mateo, J. J. (2016). Microbial Glycosidases for Wine Production. Beverages, 2(3), 20. doi: 10.3390/beverages2030020

Majchrzak, W., Motyl, I., & Śmigielski, K. (2022). Biological and Cosmetical Importance of Fermented Raw Materials: An Overview. Molecules, 27(15), 4845. doi: 10.3390/molecules27154845

Mendes Ferreira, A., & Mendes-Faia, A. (2020). The Role of Yeasts and Lactic Acid Bacteria on the Metabolism of Organic Acids during Winemaking. Foods, 9(9). doi: 10.3390/foods9091231

Motlhanka, K., Lebani, K., Boekhout, T., & Zhou, N. (2020). Fermentative Microbes of Khadi, a Traditional Alcoholic Beverage of Botswana. Fermentation, 6(2), 51. doi: 10.3390/fermentation6020051

Mudoor Sooresh, M., Willing, B. P., & Bourrie, B. C. T. (2023). Opportunities and Challenges of Understanding Community Assembly in Spontaneous Food Fermentation. Foods, 12(3). doi: 10.3390/foods12030673

Mukherjee, A., Gómez-Sala, B., O'Connor, E. M., Kenny, J., & Cotter, P. D. (2022). Global Regulatory Frameworks for Fermented Foods: A Review. Frontiers in Nutrition, 9. doi: 10.3389/fnut.2022.902642

Ngangue, R. J. E. M., Minyaka, E., Fofou, S. G. B., Koule, J. C. M., Nsoga, F. V., Ngafon, M. N., . . . Ndomou, M. (2022). Microbial Dynamics Associated With Spontaneous Fermentation of Cocoa (&Amp;lt;i&gt;Theobroma Cacao&lt;/I&gt; L.) in Cameroon and Evaluation of the Quality of Marketable Beans. International Journal of Nutrition and Food Sciences, 11(2), 38. doi: 10.11648/j.ijnfs.20221102.14

O'Toole D, K. (2019). The role of microorganisms in soy sauce production. Adv Appl Microbiol, 108, 45-113. doi: 10.1016/bs.aambs.2019.07.002

Ogawa, M., Bisson, L. F., García-Martínez, T., Mauricio, J. C., & Moreno-García, J. (2019). New insights on yeast and filamentous fungus adhesion in a natural co-immobilization system: proposed advances and applications in wine industry. Appl Microbiol Biotechnol, 103(12), 4723-4731. doi: 10.1007/s00253-019-09870-4

Pater, A., Satora, P., Zdaniewicz, M., & Sroka, P. (2022). The Impact of Dry Yeast Rehydrated in Different Plasma Treated Waters (PTWs) on Fermentation Process and Quality of Beer. Foods, 11(9). doi: 10.3390/foods11091316

Pawar, S. V., & Rathod, V. K. (2020). Role of ultrasound in assisted fermentation technologies for process enhancements. Prep Biochem Biotechnol, 50(6), 627-634. doi: 10.1080/10826068.2020.1725773

Pérez-Alvarado, O., Zepeda-Hernández, A., Garcia-Amezquita, L. E., Requena, T., Vinderola, G., & García-Cayuela, T. (2022). Role of lactic acid bacteria and yeasts in sourdough fermentation during breadmaking: Evaluation of postbiotic-like components and health benefits. Front Microbiol, 13, 969460. doi: 10.3389/fmicb.2022.969460

Perpetuini, G., Prete, R., Garcia-Gonzalez, N., Khairul Alam, M., & Corsetti, A. (2020). Table Olives More than a Fermented Food. Foods, 9(2). doi: 10.3390/foods9020178

Pielech-Przybylska, K., Balcerek, M., Dziekońska-Kubczak, U., Pacholczyk-Sienicka, B., Ciepielowski, G., Albrecht, Ł., & Patelski, P. (2019). The Role of Saccharomyces cerevisiae Yeast and Lactic Acid Bacteria in the Formation of 2-Propanol from Acetone during Fermentation of Rye Mashes Obtained Using Thermal-Pressure Method of Starch Liberation. Molecules, 24(3). doi: 10.3390/molecules24030610

Porter, T. J., Divol, B., & Setati, M. E. (2019). Lachancea yeast species: Origin, biochemical characteristics and oenological significance. Food Res Int, 119, 378-389. doi: 10.1016/j.foodres.2019.02.003

Procópio, D. P., Kendrick, E., Goldbeck, R., Damasio, A. R. L., Franco, T. T., Leak, D. J., . . . Basso, T. O. (2022). Xylo-Oligosaccharide Utilization by Engineered Saccharomyces cerevisiae to Produce Ethanol. Front Bioeng Biotechnol, 10, 825981. doi: 10.3389/fbioe.2022.825981

Rastogi, Y. R., Thakur, R., Thakur, P., Mittal, A., Chakrabarti, S., Siwal, S. S., . . . Saini, A. K. (2022). Food fermentation - Significance to public health and sustainability challenges of modern diet and food systems. Int J Food Microbiol, 371, 109666. doi: 10.1016/j.ijfoodmicro.2022.109666

Richter, F., Bindschedler, S., Calonne-Salmon, M., Declerck, S., Junier, P., & Stanley, C. E. (2022). Fungi-on-a-Chip: microfluidic platforms for single-cell studies on fungi. FEMS Microbiol Rev, 46(6). doi: 10.1093/femsre/fuac039

Rocha, J. M., Kovacevik, B., Veličkovska, S. K., Tamame, M., & Teixeira, J. A. (2023). Screening and Characterization of the Diversity of Food Microorganisms and Their Metabolites. Microorganisms, 11(5). doi: 10.3390/microorganisms11051235

Schwan, R. F., Bressani, A. P. P., Martinez, S. J., Batista, N. N., & Dias, D. R. (2023). The essential role of spontaneous and starter yeasts in cocoa and coffee fermentation. FEMS Yeast Res, 23. doi: 10.1093/femsyr/foad019

Semkiv, M. V., Ruchala, J., Tsaruk, A. Y., Zazulya, A. Z., Vasylyshyn, R. V., Dmytruk, O. V., . . . Sibirny, A. A. (2022). The role of hexose transporter-like sensor hxs1 and transcription activator involved in carbohydrate sensing azf1 in xylose and glucose fermentation in the thermotolerant yeast Ogataea polymorpha. Microb Cell Fact, 21(1), 162. doi: 10.1186/s12934-022-01889-z

Shahid, A., Nasir, K., Aslam, S., Kamran, M., Sarfraz, M. H., Saleem, H. G. M., & Khurshid, M. (2022). Potential Role of Microbiota in the Prevention and Therapeutic Management of Infectious Diseases. *Pakistan Journal of Biochemistry and Biotechnology*, *3*(1), 34-48. https://doi.org/10.52700/pjbb.v3i1.75

Šikić-Pogačar, M., Turk, D. M., & Fijan, S. (2022). Knowledge of fermentation and health benefits among general population in North-eastern Slovenia. BMC Public Health, 22(1), 1695. doi: 10.1186/s12889-022-14094-9

Soemarie, Y. B., Milanda, T., & Barliana, M. I. (2021). Fermented Foods as Probiotics: A Review. J Adv Pharm Technol Res, 12(4), 335-339. doi: 10.4103/japtr.japtr_116_21

Soltan, Y. A., & Patra, A. K. (2022). Ruminal Microbiome Manipulation to Improve Fermentation Efficiency in Ruminants. doi: 10.5772/intechopen.101582

Teleky, B. E., Martău, A. G., Ranga, F., Chețan, F., & Vodnar, D. C. (2020). Exploitation of Lactic Acid Bacteria and Baker's Yeast as Single or Multiple Starter Cultures of Wheat Flour Dough Enriched with Soy Flour. Biomolecules, 10(5). doi: 10.3390/biom10050778

Tesnière, C. (2019). Importance and role of lipids in wine yeast fermentation. Appl Microbiol Biotechnol, 103(20), 8293-8300. doi: 10.1007/s00253-019-10029-4

Tian, F., Shi, J., Li, Y., Gao, H., Chang, L., Zhang, Y., . . . Tang, S. (2021). Proteogenomics Study of Blastobotrys adeninivorans TMCC 70007-A Dominant Yeast in the Fermentation Process of Pu-erh Tea. J Proteome Res, 20(6), 3290-3304. doi: 10.1021/acs.jproteome.1c00205

Todorov, S. D., Alves, V. F., Popov, I., Weeks, R., Pinto, U. M., Petrov, N., . . . Chikindas, M. L. (2023). Antimicrobial Compounds in Wine. Probiotics Antimicrob Proteins. doi: 10.1007/s12602-023-10177-0

Tofalo, R., Fusco, V., Böhnlein, C., Kabisch, J., Logrieco, A. F., Habermann, D., . . . Franz, C. (2020). The life and times of yeasts in traditional food fermentations. Crit Rev Food Sci Nutr, 60(18), 3103-3132. doi: 10.1080/10408398.2019.1677553

Tu, W., Cao, X., Cheng, J., Li, L., Zhang, T., Wu, Q., . . . Li, Q. (2022). Chinese Baijiu: The Perfect Works of Microorganisms. Front Microbiol, 13, 919044. doi: 10.3389/fmicb.2022.919044

Versari, A., Patrizi, C., Parpinello, G. P., Mattioli, A. U., Pasini, L., Matteo, M., & Longhini, G. (2015). Effect of Co-inoculation With Yeast and Bacteria on Chemical and Sensory Characteristics of Commercial Cabernet Franc Red Wine From Switzerland. Journal of Chemical Technology & Biotechnology, 91(4), 876-882. doi: 10.1002/jctb.4652

Vicente, J., Navascués, E., Calderón, F., Santos, A., Marquina, D., & Benito, S. (2021). An Integrative View of the Role of Lachancea thermotolerans in Wine Technology. Foods, 10(11). doi: 10.3390/foods10112878

Vuyst, L. D., & Weckx, S. (2016). The Cocoa Bean Fermentation Process: From Ecosystem Analysis to Starter Culture Development. Journal of Applied Microbiology, 121(1), 5-17. doi: 10.1111/jam.13045

Wang, Q., Yang, K., Wei, X., Qiao, W., & Chen, L. (2022). Untargeted metabolomics analysis reveals dynamic changes in co-fermentation with human milk-derived probiotics and Poria cocos. Front Microbiol, 13, 1032870. doi: 10.3389/fmicb.2022.1032870

Watanabe, D. (2024). Sake yeast symbiosis with lactic acid bacteria and alcoholic fermentation. Biosci Biotechnol Biochem, 88(3), 237-241. doi: 10.1093/bbb/zbad167

White, K. D., Yu, J.-H., Eraclio, G., Bello, F. D., Nauta, A., Mahony, J., & Sinderen, D. v. (2022). Bacteriophage-Host Interactions as a Platform to Establish the Role of Phages in Modulating the Microbial Composition of Fermented Foods. doi: 10.20517/mrr.2021.04

Xia, Y., Luo, H., Wu, Z., & Zhang, W. (2023). Microbial diversity in jiuqu and its fermentation features: saccharification, alcohol fermentation and flavors generation. Appl Microbiol Biotechnol, 107(1), 25-41. doi: 10.1007/s00253-022-12291-5

Yang, L., Fan, W., & Xu, Y. (2020). Metaproteomics Insights Into Traditional Fermented Foods and Beverages. Comprehensive Reviews in Food Science and Food Safety, 19(5), 2506-2529. doi: 10.1111/1541-4337.12601

Yu, J., Ma, D., Qu, S., Liu, Y., Xia, H., Bian, F., . . . Bi, Y. (2020). Effects of Different Probiotic Combinations on the Components and Bioactivity of Spirulina. Journal of Basic Microbiology, 60(6), 543-557. doi: 10.1002/jobm.201900699

Zapaśnik, A., Sokołowska, B., & Bryła, M. (2022). Role of Lactic Acid Bacteria in Food Preservation and Safety. Foods, 11(9). doi: 10.3390/foods11091283

Zhang, H., Tan, Y., Wei, J., Du, H., & Xu, Y. (2022). Fungal Interactions Strengthen the Diversity-Functioning Relationship of Solid-State Fermentation Systems. Msystems, 7(4). doi: 10.1128/msystems.00401-22

Zhang, J., Fang, L., Huang, X., Ding, Z., & Wang, C. (2022). Evolution of Polyphenolic, Anthocyanin, and Organic Acid Components During Coinoculation Fermentation (Simultaneous Inoculation of LAB and Yeast) and Sequential Fermentation of Blueberry Wine. Journal of Food Science, 87(11), 4878-4891. doi: 10.1111/1750-3841.16328

Zhao, N., Kokawa, M., Amini, R. K., Dong, W., & Kitamura, Y. (2023). Isolation of Yeast and LAB from Dry Coffee Pulp and Monitoring of Organic Acids in Inoculated Green Beans. Foods, 12(13). doi: 10.3390/foods12132622

Zhou, Z., Ren, B., Li, J., Zhou, X., Xu, X., & Zhou, Y. (2022). The Role of Glycoside Hydrolases in S. gordonii and C. albicans Interactions. Appl Environ Microbiol, 88(10), e0011622. doi: 10.1128/aem.00116-22