

## The Role of Yeasts in Traditional and Industrial Food Fermentations: Bread, Dairy and Beverages

### Muhammad Suleman Najib\*

Food Science and Nutrition, University of Veterinary and Animal Sciences (UVAS)

Email: Suleman307@gmail.com

### Iqra Sattar

Food Science and Nutrition, University of Sargodha Pakistan

Email: iqrasattar1146@gmail.com

### Rabia Tariq Khan\*

Department of Agronomy, Faculty of Agriculture, University of Agriculture, Faisalabad Email: RabiaTariqKhan@outlook.com

### Nida Shahzadi

National Institute of Food Science and Technology (NIFSAT), Faculty of Food Nutrition and Home Sciences (FFNHS), University of Agriculture, Faisalabad

Email: Shahzadinida041@gmail.com

### Muhammad Taha

National Institute of Food Science and Technology (NIFSAT), Faculty of Food Nutrition and Home Sciences (FFNHS), University of Agriculture, Faisalabad

Email: Muhammadtaha525@gmail.com

### Ameer Jan

University of Makran Email: ameerjan@uomp.edu.pk

#### Author Details

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Corresponding E-mail & Author\*:

**Muhammad Suleman Najib**

Email: Suleman307@gmail.com

**Rabia Tariq Khan**

Email:

RabiaTariqKhan@outlook.com

#### Abstract

Yeasts are unicellular eukaryotic organisms which have been essential to food fermentation for thousands of years. This review addresses the various roles played by yeasts in the traditional and industrial manufacturing of food products such as bread, dairy products and beverages. In all these applications, *Saccharomyces cerevisiae* is the dominant species due to its ability to efficiently metabolize carbohydrates, its leavening properties and its flavor creating capabilities. Recent research has however highlighted the potential of non-*Saccharomyces* yeasts, including the aroma enhancing *Torulaspora delbrueckii*, the exopolysaccharide producing *Kluyveromyces marxianus*, stress-tolerant *Pichia kudriavzevii* and the phytase-producing *Lachancea thermotolerans*. Yeasts are used in bread making as leavening and flavour development agents; and some non-conventional species are being evaluated for clean label products. Yeasts are mainly used in dairy fermentations for surface-ripened

cheeses and fermented milk products to aid in proteolysis, lipolysis, and in order to reduce off-flavour. In the beverage industry, there is the most variety in the use of yeast in fermentations, as in wine, beer, and spirits production, both pure and mixed culture approaches are used. Through metabolic engineering, such as with the application of the CRISPR/Cas9 genome editing system, fermentation capabilities have been

optimized for strains to yield greater amounts of desirable fermentation products, as well as stress resistance and targeted flavor compound production. In addition, yeasts are now known to be promising biofactories for the production of emulsifiers, organic acids and other value-added products in the frame of circular bioeconomy. This review aims to build a summary of the existing knowledge on yeast metabolic pathways, strain selection strategies, and industrial applications of yeast-mediated food fermentation, and to envision future research avenues for yeast in food fermentation.

## Introduction

Fermentation is one of the oldest biotechnological processes known to humankind, dating back to around 10,000 years ago for fermented honey, fermented fruits, and fermented rice, and around 6000–7000 BC for grape fermentation, bread production and cheese making (El-Sheikha and Hu, 2020). Although ancient civilizations were not aware of the microbiological agents that cause these changes, they have been able to control microbial metabolism for food preservation and enhancement of nutritional and sensory properties. Fermentation is still the driving force in the world food system today, and global demand for fermented food products is substantial, with fermented food products being perceived as being natural, functional and flavoursome (Malekijahan *et al.*, 2025).

Yeasts are one of the most interesting groups of microorganisms, which have an important role in food fermentation. The metabolic versatility of these single cell fungi allows them to produce a variety of carbon dioxide, ethanol and an amazing range of VOCs which can be used to create and impart product attributes. The genus *Saccharomyces*, notably *Saccharomyces cerevisiae*, has been used as a workhorse for industrial fermentation for centuries, because of its robustness, genetic tractability and Generally Recognized as Safe (GRAS) status (Tofalo *et al.*, 2020). Over the last two decades, however, a paradigm shift has occurred in the science of yeasts as fermenters, with a shift from the *Saccharomyces*-yeast-centered perspective to the appreciation of the functional diversity that is provided by non-*Saccharomyces* yeasts (also called non-conventional yeasts).

The purpose of this review is to give a broad picture of the various uses of yeast in three major categories of food fermentation, baked goods, dairy products and beverages. We explore the metabolic pathways of yeast functional properties, their similarities and differences between traditional and industrial use, and new developments in yeast strain engineering, as well as future trends and challenges such as precision fermentation and sustainable production methods.

## Yeast Biodiversity and Metabolic Foundations

### Taxonomic Diversity of Fermentation-Associated Yeasts

The yeast species relevant to food fermentation span multiple genera, each offering distinct metabolic capabilities. Table 1 summarizes the major yeast species encountered in food fermentations, their primary applications, and key functional properties.

**Table 1. Major Yeast Species in Food Fermentations**

Species	Primary Applications	Key Functional Properties
<i>Saccharomyces cerevisiae</i>	Bread, beer, wine, spirits	High leavening capacity, ethanol production, flocculation, stress tolerance
<i>Torulaspora delbrueckii</i>	Wine, bread	Aroma complexity, low volatile acidity, glycerol production
<i>Kluyveromyces marxianus</i>	Dairy, bread, beverages	Thermotolerance, lactose utilization, aroma enhancement

<i>Kluyveromyces lactis</i>	Dairy (whey fermentation)	Lactose fermentation, lactic acid production
<i>Lachancea thermotolerans</i>	Wine	Lactic acid production (acidification), glycerol enhancement
<i>Pichia kudriavzevii</i>	Sourdough, beverages	Multi-stress tolerance, phytase activity, EPS production
<i>Wickerhamomyces anomalus</i>	Sourdough, beer	Killer toxin production, ester formation
<i>Candida utilis</i>	Fermented plant products	Lignocellulosic inhibitor tolerance, protein enrichment
<i>Hanseniaspora spp.</i>	Wine (early fermentation)	Fruity ester production
<i>Papiliotrema terrestris</i>	Bread	Exopolysaccharide production, biocontrol activity

### Core Metabolic Pathways

The metabolic processes of yeast during fermentation revolve around the breakdown of carbohydrates to generate carbon dioxide, ethanol and a multitude of secondary metabolites that play a role in flavor and aroma (Maicas, 2020).

In the Embden-Meyerhof-Parnas (glycolytic) pathway, yeasts convert hexose sugars into pyruvate under anaerobic or semianaerobic conditions that are typical of food fermentations. Pyruvate is then decarboxylated to acetaldehyde and reduced to ethanol, and regeneration of NAD<sup>+</sup> is necessary to maintain the progression of glycolytic flux. In many yeasts, the fermentative nature of the metabolism also persists during aerobic conditions, in the case of *S. cerevisiae* this phenomenon is known as the Crabtree effect (Dzialo *et al.*, 2017).

Yeasts produce many flavor compounds (Chen *et al.*, 2023), other than the primary metabolites: Higher alcohols (fusel alcohols): formed from the Ehrlich pathway which consists of transamination, decarboxylation and reduction of the amino acids during their catabolism Esters – Condensation of alcohols with acyl-CoA by alcohol acyltransferase for fruity-floral aromas. - Carbonyl compounds: Diacetyl (buttery), acetaldehyde (green apple) and other ketones. Sulfur compounds: Tropical notes from thiols and sulfides, cooked vegetable notes as well.

These are modulated by fermentation conditions, strain genotype and microbial interactions which allows the targeted manipulation for desired sensory outcomes (Liu *et al.*, 2020).

### The role of yeasts in bread making

#### The importance of yeasts in bread making

Many people still view the pit as a traditional leaven and flavor. The pit is still considered a traditional leaven and flavour by many. Fermentation of bread is the oldest and most common use of yeast in food production. Gluten forms a network in bread dough, which becomes more porous due to the metabolic activity of yeasts that convert fermentable sugars (glucose, fructose, sucrose and maltose) into carbon dioxide, causing the dough to rise. The leavening process also results in the formation of ethanol and volatile organic compounds which are responsible for the aroma of baked bread (Struyf *et al.*, 2017).

For more than a century, *Saccharomyces cerevisiae* was the preferred baking yeast because of its ability to produce CO<sub>2</sub> quickly, perform well under baking conditions, and withstand stresses like osmotic pressure (due to the addition of sugar), freeze-thaw (from frozen dough) and oxidative stress (Banwo *et al.*, 2020).

### Challenges in Modern Bread Production

Contemporary baking presents several challenges for yeast performance.

Table 2 summarizes the constraints encountered in different dough systems and emerging solutions.

**Table 2. Yeast Performance Constraints and Engineering Solutions in Bread-Making**

Dough Type	Primary Challenge	Consequence	Strain Engineering Solution
Lean dough (low sugar, 0-2%)	Glucose repression of maltose utilization	Reduced leavening in baguettes, ciabatta	Deletion of glucose repression genes (e.g., <i>MIG1</i> )
Sweet dough (high sugar, 20-30%)	Osmotic stress	Cellular dehydration, decreased CO <sub>2</sub> production	Glycerol overproduction (engineered <i>GPD1</i> , <i>GPP2</i> )
Frozen dough	Ice crystal formation, freeze-thaw cycles	Cell membrane damage, reduced viability after thawing	Enhanced trehalose accumulation, glycerol biosynthesis
Clean-label products	Absence of chemical preservatives	Mold contamination, reduced shelf-life	Antimicrobial compound production (killer toxins, organic acids)

New developments with the CRISPR/Cas9 genome editing technology have paved the way for the targeting and editing of baker's yeast strains for industrial applications without leaving any markers behind. The deletion of the glucose repression genes in the Korean traditional nuruk-derived strain of *S. cerevisiae*, SPC-SNU 70-1, improved maltose utilization and leavening in lean doughs, as shown by Cha *et al.* (2025). At the same time, the overexpression of glycerol biosynthesis genes (*GPD1* and *GPP2*) enhanced osmotic tolerance in sweet doughs and freeze tolerance which is a significant commercial trait in frozen dough products (Cha *et al.*, 2025).

### Emerging Non-Saccharomyces Yeasts in Baking

The challenges of using *S. cerevisiae* in specific applications, along with consumer preferences for a wide variety of flavors and clean-label products, have stimulated a search for non-conventional baking yeasts (Sadeghi *et al.*, 2025). There are some species showing good techno-functional potential: Non-Saccharomyces yeasts have their own unique volatile profiles which provide aroma enhancement to complement or surpass that of the *Saccharomyces cerevisiae*. The yeast species *Torulaspora delbrueckii* and *Wickerhamomyces anomalus* produce high concentrations of 2-phenylethanol (rose-like) and fruity/ester esters (clove-like) respectively (Sadeghi *et al.*, 2023).

The strains of *Papiliotrema terrestris* and some strains of *Pichia kudriavzevii* produce exopolysaccharide (EPS) which acts as natural conditioner for dough. EPS addition has positive effects such as enhancing dough rheology, increasing specific volume of bread, decreasing storage firmness and extending the shelf-life without the use of mold (Sadeghi *et al.*, 2025).

### Phytase Activity:

Many non-conventional yeasts have the ability to break down phytic acid which is an anti-nutrient substance that chelates minerals and thus decreases their bioavailability. Different breads (sourdough and yeast-leavened) are better for the absorption of minerals (iron, zinc, calcium) due to phytate degradation (Tofalo *et al.*, 2020).

Synergistic interactions between non-*Saccharomyces* yeasts and *S. cerevisiae* in dough fermentation were found. The co-culture of *P. Terrestris* or *T. delbrueckii* with other yeast species such as *S. cerevisiae* can result in more biofortified CO<sub>2</sub> production than when using only one species, and boost volatile compound profiles as well (Sadeghi *et al.*, 2025).

### Sourdough Fermentation

Natural sourdough is a system of fermentation consisting of lactic acid bacteria (LAB) and yeasts. LAB are mainly responsible for acid production whereas yeasts produce characteristic flavour substances and provide leavening (in addition to or in place of baker's yeast). Mature sourdoughs generally contain *S. cerevisiae*, *Kazachstania* spp., *Pichia* spp. and *Candida* spp., and their composition is dependent on geographical origin, flour type and maintenance conditions of the sourdoughs (Zhou and Li, 2021)

### The yeast in Dairy Fermentations. Yeast in Dairy Fermentations

Yeast diversity in dairy products. 4.1 Yeasts diversity in dairy products. In fermentations like bread, beverage and dairy, the yeasts are usually used as the main microorganism but in dairy fermentations the LAB are more dominant with the yeasts playing supporting or secondary roles. However, yeasts play an important role in certain categories of dairy products (Tofalo *et al.*, 2020).

**Table 3. Yeast Roles in Dairy Fermentation**

Product Category	Yeast Species	Functional Contribution
Surface-ripened cheeses (e.g., Camembert, Brie)	<i>Debaryomyces hansenii</i> , <i>Kluyveromyces marxianus</i> , <i>Yarrowia lipolytica</i>	Proteolysis, lipolysis, deacidification, aroma development (sulfur compounds)
Blue cheeses	<i>Debaryomyces hansenii</i> , <i>Candida</i> spp.	Secondary ripening, flavor modulation
Kefir	<i>Kluyveromyces marxianus</i> , <i>Saccharomyces cerevisiae</i> , <i>Torulasporea delbrueckii</i>	Ethanol production, CO <sub>2</sub> (effervescence), flavor complexity
Fermented milks (various)	<i>Kluyveromyces lactis</i> , <i>Kluyveromyces marxianus</i>	Lactose utilization, vitamin production
Whey fermentation	<i>Kluyveromyces lactis</i> , <i>Kluyveromyces marxianus</i>	Valorization of dairy by-products, production of bioethanol, single-cell protein

### Functional Properties in Cheese Ripening

Surface-ripened cheeses (soft cheeses with white rinds) are ripened with the help of microbial organisms including mold *Penicillium camemberti* and the resident yeast in the cheese. *Debaryomyces hansenii* is the most abundant yeast found on the surface of cheese, and it carries out several important roles (Tofalo *et al.*, 2020):

Yeasts deacidify by converting LAB produced lactic acid to produce a surface pH >6.0. This change in pH is necessary for the next stage of growth of *P. camemberti* and the action of the ripening enzymes.

Extracellular proteases and lipases found in the yeast break down milk proteins and triglycerides into amino acids and free fatty acids, which can be used to generate flavor volatiles.

When yeasts catabolize methionine, they produce sulfur volatiles that give ripened cheeses the characteristic cabbage, garlic and mushroom aroma.

Some yeast strains are able to metabolize to remove undesirable compounds such as short-chain fatty acids (butyric acid, caproic acid, caprylic acid), which provide a rancid or sweaty taste to the profile of cheeses – a "cleaning" effect. Yeasts can also be used to produce lactic acid.

Traditional lactic acid (LA) producers are the lactic acid bacteria while yeasts are beneficial for LA production in industry. Yeasts are also better adapted to low pH thresholds (pH <4.0), they are able to grow on a wider range of substrates, such as lactose and pentoses, and can be genetically and metabolically engineered (Borzęcka *et al.*, 2025).

*Kluyveromyces lactis* and *K. marxianus* are especially well suited for the production of LA for the dairy industry, as they will readily convert lactose from cheese whey, which is a large by-product of the dairy industry, into LA. This application represents circular economy concepts, by turning waste into valuable chemicals. LA titers as high as those of LAB have been obtained using engineered *S. cerevisiae* strains carrying heterologous lactate dehydrogenase (LDH) genes, but with improved acid tolerance of engineered strains and easy downstream processing (Borzęcka *et al.*, 2025).

## **The use of yeasts in beverage fermentations.**

### **Wine Fermentation**

Wine fermentation is the area of yeast application that is most widely studied and technologically advanced, and is a blend of old and new technologies involving yeast development and selection. Traditional wine fermentations used indigenous yeasts that exist on the surface of the grapes and equipment in the winery, and produced a variety of results. Currently, a majority of the winemaking industry utilize starter cultures that are a selection of *S. cerevisiae*, providing consistent fermentation dynamics and sensory characteristics. The spontaneous fermentations, however, as a result of the sequential succession of yeasts, have become more complex and more fascinating, leading to renewed interest in the use of mixed cultures (Maicas, 2020).

Non-*Saccharomyces* yeasts such as *Hanseniaspora* species (mainly *Hanseniaspora uvarum*), *Candida* species, *Metschnikowia* species, *Torulaspota* species and *Lachancea* species and also *Saccharomyces* species, with the exception of *Saccharomyces cerevisiae* and *Saccharomyces kuyumstshievii*, dominate the early stages of spontaneous wine fermentation, producing enzymes and metabolites that affect wine aroma. Then, ethanol-tolerant *S. cerevisiae* is used to finish the fermentation. Selected non-*Saccharomyces* strains when controlled co-inoculated with *S. cerevisiae* strains are beneficial in several ways (Dzialo *et al.*, 2017):

Both species, *T. delbrueckii* and *M. pulcherrima*, contribute to higher levels of terpenes, esters and thiols, enhancing aroma complexity. Produce glycerol for increased wine body and mouthfeel  
Acid modulation: *L. thermotolerans* produces lactic acid, which decreases the amount of lactic acid added into warm climate wines. Some non-*Saccharomyces* strains reduce volatile acidity (ethanol, and acetic acid)

### **Beer Fermentation**

There are two main types of fermentation used in the beer industry (Steensels and Verstrepen, 2014): Top fermenting: Ale fermentation yeast, *S. cerevisiae*, at 15-24°C and yields complex aromas with esters. - Lager fermenters are made up of *Saccharomyces pastorianus* (bottom fermenting) at 4-12°C to produce a cleaner and crisp profile. Craft beer has spurred the use of emerging yeast varieties, e.g., *T. delbrueckii*, *L. thermotolerans* and *Brettanomyces* (providing unique, often clove, horse blanket, medicinal notes). Controlled mixed fermentation (CMF) with *Brettanomyces* and LAB is becoming more popular for sour beer production as alternative to traditional spontaneous fermentation (Steensels and Verstrepen, 2014).

## **Spirit Production**

Distilled alcohol (whiskey, brandy, rum, vodka) starts with yeast fermentation of grain, fruit, sugarcane or other carbohydrates. The profile of congeners (all other volatiles besides ethanol, that survive distillation and contribute to spirit character) depend markedly on the fermentation conditions (temperature, pH, nutrient availability, yeast strain). In order to obtain desirable sensory characteristics (Maicas, 2020), the production of congeners is carefully controlled by selecting the strains and by process control.

## **Incorporate the genes**

It control the production of specific metabolites. Introduce strain development and metabolic engineering.

## **Traditional and Molecular Approaches**

There are several strategies that are being used to optimise yeast strains for food fermentation, including classical strain selection and precision genome editing: The process of screening and selection of natural variants with desirable characteristics (stress resistance, specific flavour, flocculation properties etc.) is still a core process. The traditional mutagenesis (such as UV irradiation, chemical mutagens) has produced improved strains with off-target effects, which takes a lot of back-crossing (Benjaphokee *et al.*, 2012).

Placing yeast populations under intense selection for specific stresses (high sugar, low pH, high temp, low temp) enriches for beneficial mutations, which is called “Adaptive Laboratory Evolution” (ALE). The non-GMO nature of ALE has been a concern for consumers in the face of genetically modified organisms (GMO) (Stanley *et al.*, 2010).

A revolutionary genome editing technique, CRISPR/Cas9, allows for genome modification without scarring. For baking yeast applications, deleting glucose repression genes (Krogerus *et al.*, 2021; Cha *et al.*, 2025) and overexpressing glycerol biosynthesis genes (Krogerus *et al.*, 2021; Cha *et al.*, 2025) has been achieved without introducing foreign DNA, thus avoiding classification of these yeasts as GMOs as per some regulations.

## **Precision Fermentation**

In addition to traditional fermentation, yeasts are platforms for precision fermentation, the creation of selected food ingredients, proteins and bioactives. The engineered yeast strains produce: -

### **Milk proteins (casein, whey)**

Animal free dairy - The egg proteins (ovalbumin) for egg substitutes –

**Heme proteins** of plant-based meat analogs Flavor compounds (vanillin, nootkatone, lactones)

**Sweeteners** (thaumatin, mogrosides) In precision fermentation, the separation of growth, in which biomass is produced, from product synthesis allows for the production of high levels of target molecules with sustainable feedstocks (Cho *et al.*, 2025).

## **Challenges and Regulatory Considerations**

Although there are technical advances, there are still a few obstacles to the use of engineered yeast strains for food fermentation (Mertens *et al.*, 2019): Commercial use of genetically modified food yeasts is limited by consumer acceptance, especially in Europe, where labeling policies are in place. The use of non-GMO alternatives (ALE-selected strains, native non-*Saccharomyces* yeasts) may be subject to fewer regulatory hurdles. Regulatory Framework: International commercialization is complicated by jurisdictional differences regarding GM regulation. CRISPR-edited strains without transgenes could be considered conventional (in the USA and Japan) or as GMOs

regulated (in the EU), which would lead to market segmentation. Strain stability should be ensured in the scaling up of performance from lab to industrial production. Caution is needed in quality management because of genetic drift, plasmid loss (recombinant strains) and phenotypic instability.

## Yeasts as Sustainable Biofactories

### By-product Valorization

Sustainable food production via valorisation of by-products is a great opportunity based on yeast mediated fermentations: The use of cheese whey as a waste stream is effectively converted to ethanol, single cell protein or organic acids using the *Kluyveromyces* species, decreasing pollution of the environment (Borzęcka *et al.*, 2025).

Biofuel and BioChemical Production from Non-food Biomass: Pentose sugars from agricultural residues can be fermented by engineered strains of *Saccharomyces cerevisiae* and *Candida utilis* to generate biofuel and biochemicals (Gutiérrez-Ríos *et al.*, 2022).

According to the circular economy concept, food processing waste can be used to produce added value products through food waste fermentation using mixed yeast cultures (Malekijahan *et al.*, 2025).

### Yeast-Derived Emulsifiers

Yeast biomass and yeast cell wall fractions (mannoproteins, glucans, exopolysaccharides) are effective food emulsifiers that can be used as alternative to synthetic or animal emulsifiers (Shokri *et al.*, 2026).

### Applications include:

Mannoproteins obtained from cell wall of *S. cerevisiae* and *S. uvarum* are used as a stabilizer in oil-in-water emulsions in salad dressings, mayonnaise and beverages, and are responsible for positive sensory properties (De Melo *et al.*, 2015). Inactivated yeast cells can be used as Pickering emulsion stabilizers, such as plant-based meat and dairy alternatives (Shokri *et al.*, 2026). The glycolipids produced by yeast, such as biosurfactant sophorolipids made by the yeast *Candida bombicola*, have good emulsifying properties, are low in toxicity and readily biodegradable (Hirata *et al.*, 2009).

Table 4 summarizes yeast-derived emulsifier applications

**Table 4. Yeast-Derived Emulsifiers and Food Applications**

Emulsifier Type	Source	Application	Key Advantages
Mannoproteins	<i>S. cerevisiae</i> , <i>S. uvarum</i>	Salad dressings, beverages	Clean-label, flavor enhancement
Yeast cell wall fractions	<i>S. cerevisiae</i>	Bakery, meat analogs	Clean-label, GRAS status
β-Glucans	<i>S. cerevisiae</i>	Dairy, frozen desserts	Viscosity enhancement, prebiotic
Exopolysaccharides	<i>P. terrestris</i> , <i>P. kudriavzevii</i>	Bakery	Texture improvement, shelf-life extension
Sophorolipids	<i>Candida bombicola</i>	Processed foods	Biodegradable, low toxicity

## Yeast Interactions in Mixed Fermentations

### Yeast-Bacteria Interactions

The fermentations of many foods are carried out by complex microbial consortia that include interaction between yeasts and bacteria, including LAB (Liu *et al.*, 2020):

In sourdough and other cheese fermentations, yeast metabolism can produce growth factors (vitamins, amino acids) which can stimulate the growth of LAB, while LAB can also produce organic acids which can inhibit the growth of spoilage organisms, so that it can form a stable and productive ecosystem (Zhou and Li, 2021).

Competition: Fermentable sugars and other nutrients are competed for by yeasts and LAB. Fermentation conditions (temperature, pH, oxygen) affect competition with the possibility of process control to benefit desired populations (Paulino *et al.*, 2021). Consortia composition is stabilized by mutual inhibition, with the production of sulfur dioxide and antimicrobial peptides by *S. cerevisiae* and LAB, which produce bacteriocins and organic acids, respectively. (Wang *et al.*, 2021; Chen *et al.*, 2017).

### **Yeast-Yeast Interactions**

The interaction of the *S. cerevisiae* with non-Saccharomyces yeasts can be in three different ways (Sadeghi *et al.*, 2023): Neutral – When there is no major influence between the two groups in their development.

**Amensalism:** One strain makes inhibitory substances (ethanol production by *S. cerevisiae* inhibits sensitive non-Saccharomyces yeasts)

**Synergistic:** Complementary metabolism - The productivity of the system increases as a result of the complementary metabolism. If these interaction mechanisms are understood, it is possible to make effective mixed starter cultures.

### **Future Perspectives and directions for research**

#### **Expanding Non-Saccharomyces Characterization**

Although there is an increasing interest in the use of yeast for food fermentation, most of the non-Saccharomyces yeast species are poorly explored for such applications. A high throughput screening of biodiversity collections, coupled with genomic and metabolomic characterization will yield novel strains with valuable functional properties (Tofalo *et al.*, 2020).

#### **Systems Biology and Predictive Modeling**

The combination of omics data (genomics, transcriptomics, proteomics, metabolomics) and fermentation kinetics allows the prediction of yeast performance. This will speed up the selection of strains, optimize fermentation conditions and minimize the need for empirical testing (Dzialo *et al.*, 2017).

#### **Consumer-Guided Strain Development**

Clean Label, Natural, Low Processing items remain driving preferences in the fermentation industry. Strain development needs to achieve a combination of technical performance and consumer-acceptable production methods (preferring non-GMO approaches like ALE, native strain selection) (Mertens *et al.*, 2019).

#### **Climate Adaptation**

Climate change impacts the fermentation agriculture (grape composition, grain quality) and the fermentation processes (temperatures, water availability). Enhanced thermotolerant, osmotolerant and substrate flexible yeast strains will prove to be crucial for resilient fermentation systems (Shima and Takagi, 2009; Aslankoohi *et al.*, 2015).

### **Conclusion**

Traditional and industrial food fermentations rely on yeast as essential agents and key components in the production of food products of special sensory, nutritional and

preservative properties such as breads, dairy products and beverages. *Saccharomyces cerevisiae* is the most important species in all applications with its great performance and genetic manipulation. With these increasingly recognized non-*Saccharomyces* yeasts have come a wealth of functional versatility and potential solutions to a variety of problems, including clean label bread making and sustainability of dairy waste valorization. The application of genome editing, systems biology and precision fermentation technology is continually pushing boundaries of yeast functionality, allowing for specific yeast flavor profiles, stress resistance and metabolite production to be targeted for improvement. At the same time, valorisation of by-products and use of sustainable feedstocks when using yeast fermentation makes yeasts important players in sustainable food systems. The future of yeast fermentation science is perfectly poised to merge with traditional knowledge and the new biotechnology, driven by consumer demand for foods that are natural, tasty, and produced sustainably. Yeast research will continue to contribute to the improvement of food quality and sustainability in the years to come, bridging these domains.

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