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COMPARISON OF FERMENTATION AND MEDICAL POTENTIALS OF *Saccharomyces* WITH *Wickerhamomyces* GENERA

COMPARACIÓN DEL POTENCIAL FERMENTATIVO Y MÉDICO DE LOS GÉNEROS *Saccharomyces* CON *Wickerhamomyces*

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Abstract

Comparative assessment of two different yeast genera, *Saccharomyces* and *Wickerhamomyces* is carried out regarding industrial and medical applications with special emphasis on their role in bioethanol production. Since second generation ethanol production from lignocellulosic material has become a hot topic of research due to its noncompetitive nature with food, economically feasible conversion of lignocellulosic biomass requires an organism capable of metabolizing both the hexoses and pentoses simultaneously. *Saccharomyces* genus which is in extensive use currently for bioethanol production can effectively convert hexoses into ethanol but unable to metabolize xylose. However, *Wickerhamomyces* genus has the potential to convert both the pentoses as well as the hexoses into bioethanol. Additionally, due to its glycosidase production ability, *Wickerhamomyces* genus is tolerant to high levels of glucose and ethanol. Furthermore, the capabilities of the two genera with respect to their role in probiotics, antimicrobial agents, food, beverages, biosorption, whole cell biocatalyst, and pectinolytic enzyme production have also been compared in this review.

Keywords: mycoproducts, lignocellulose, antimicrobial, synergism, biosorption.

Resumen

Se realizó una evaluación comparativa de dos géneros diferentes de levadura, *Saccharomyces* y *Wickerhamomyces* en aplicaciones industriales y médicas, con énfasis especial en su rol en la producción de bioetanol. Dado que la producción de etanol de segunda generación a partir de material lignocelulósico se es un tópico actual de investigación debido a su naturaleza no competitiva con los alimentos, la conversión económicamente viable de la biomasa lignocelulósica requiere un microorganismo capaz de simultáneamente tanto hexoxas como pentosas. El género *Saccharomyces* se usa actualmente extensamente en la producción de bioetanol, ya que convierte eficientemente las hexosas en etanol, pero no escapaz de metabolizar la xilosa. Sin embargo, el género *Wickerhamomyces* posee el potencial para convertir tanto pentosas y hexosas en bioetanol. Adicionalmente, debido a su habilidad para producir glucosidasa, el género *Wickerhamomyces* es tolerante a altas concentraciones de glucosa y etanol. Más aun, la capacidad de ambos géneros con respecto a su rol en probióticos, agentes antimicrobianos, alimentos, bebidas, biosorción, biocatálisis de células completas y producción de enzimas pectinolíticas también son comparadas en esta revisión.

Palabras clave: micoproductos, lignocelulosa, antimicrobiano, sinergismo, biosorción.

1 Introduction

Yeast is an umbrella term comprising of a huge collection of various single celled fungi. *Saccharomyces* is a genus which mainly consists of budding yeast. In the intestinal microbiota, it is considered to be the main part of residual microbial system. For a long time, yeasts belonging to the genus *Saccharomyces* have been used as a model in biomedical research. Also, *Saccharomyces* can withstand high ethanol concentrations (Moysés *et al*., 2016). They seem to possess cell processes similar to the metazoan systems and can serve as model organisms for larger eukaryotes. Most of its species are non-pathogenic causing no threats to human beings. However, some species act as opportunistic pathogens. Additionally, processes of recombination and transmission of genetic material can be easily studied by using them as an important tool. The

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first eukaryotic organism to get its entire genome sequenced is *S. cerevisiae*. Like a typical eukaryotic cell, it possesses well organized membrane bounded organelles for example; nucleus, mitochondria and Golgi complex (Wild *et al*., 2018, Shao *et al*., 2018).

Yeast belonging to *Wickerhamomyces* is abundantly found in natural environments. It is known to be encountered in different kinds of fermentation, may be leading to positive or negative effects. Its member *W. anomalus* is known to be a part of normal microbiota of skin and oropharynx of human (Robnett *et al*., 2008). Since it lacks antifungal drug resistance, it is considered to possess less virulence as only a few fatal cases have been reported by the infection of yeast itself. The basic characters required to induce pathogenicity in an organism are absent in this yeast (Vrancken *et al*., 2010). It is an opportunistic pathogen because of its capability to grow at 37oC. Also, it has great physiological versatility and has ability to metabolize various types of carbon and nitrogen sources. Additionally, the survival rate of this yeast under adverse environmental conditions is high. Capability to grow at lower water activity, survival in osmotic and pH stress environment, flourishing in the presence of lactic acid bacteria and last but not the least, the production of killer toxins are all the attributes of this yeast. All these characteristics help *Wickerhamomyces* to outcompete well adapted yeasts and fungi (Daniel *et al*., 2010, Yan *et al*., 2019).

2 Second generation bioethanol

For a long time, cornstarch and sugarcane have been used as the sources of glucose for the microbial fermentation of this sugar into fuels and chemicals. There is a competition for these substrates to be used as both food and fuel since sugar and starch are essential components of food and animal feed. Because of this competition, the process of bioethanol production from lignocellulosic materials is being researched widely; as the lignocellulosic biomass is rich in fermentable sugars which make it a potential feedstock for the production of bioethanol. Cellulose, hemicellulose and lignin are the important structural components of this lignocellulosic material. Saccharification of this biomass makes availability of only cellulose and hemicelluloses to be used as substrates for the production of bioethanol in the process known as fermentation (Jansen *et al*., 2017, Jönsson *et al*., 2013).

Hydrolyzate is a mixture of high amounts of glucose and xylose, low concentration of galactose, arabinose and mannose, and inhibitory compounds produced as a result of hydrolysis of plant material in a pretreatment process. The medium used for the production of bioethanol by the fermentation process is this hydrolyzate (Hossain *et al*., 2013). Hexoses are the main constituents present in the hydrolyzates of cornstarch and sugarcane while hexoses and pentoses both are important constituents of the cellulosic material. Cellulases from fungi are mainly responsible for the hydrolysis of cellulose into hexoses. The primary product produced as a result of hydrolysis of cellulose is cellobiose. β-glucosidases are involved in further hydrolysis of this cellobiose into glucose. When hemicelluloses are treated with an acid, pentoses like xylose and arabinose are released. About 70% cellodextrins, glucose and around 30% xylose are present in the hydrolyzates of plant material (Haq *et al*., 2011, Li *et al*., 2019).

Efficient production of bioethanol from hydrolyzates needs an organism with the following two attributes. 1) It should be capable of utilizing hexoses as well as pentoses. 2) It should exhibit resistance to inhibitors present in the hydrolyzate (Hossain *et al*., 2013).

2.1 Yeast in ethanol production

Wickerhamomyces anomalus previously known as *Hansenula anomala*, yeast isolated from grass silage has been identified as a potential organism which possesses both of the above mentioned attributes for the successful production of bioethanol from lignocellulosic material. It produces important enzymes which can simultaneously ferment pentoses and hexoses to ethanol even in high ethanol concentration (Perez *et al*., 2018). With high toxicity levels as it possesses the ability to produce bacteriocin like compounds and some organic derivatives, this strain has a great potential to produce bioethanol without the fear of contamination by other microbes (Coda *et al*., 2011). They are also able to consume nitrate as a nitrogen source (Lorenzini *et al*., 2018, Limtong *et al*., 2012). Moreover, In the presence of glycosidase enzyme, this yeast shows tolerance to high concentrations of glucose and ethanol (Madrigal *et al*., 2012, Cunha *et al*., 2019).

Hexoses like glucose, mannose, and galactose are effectively converted into ethanol by *Saccharomyces cerevisiae*. It is also known to show tolerance for inhibitory compounds in the lignocellulosic

Table 1. Comparison of different carbon sources utilization by Sacchromyces and *Wickerhamomyces* sp.

Carbon source	Saccharomyces	Wickerhamomyces	References
Glucose	+	+	(Luyten *et al*., 2002; Pinu *et al*., 2014)
Fructose	+	+	(Groenewald *et al*., 2011; Pinu *et al*., 2014)
Galactose	+	+	(Groenewald *et al*., 2011; Passoth *et al*., 2011)
Sorbose	+	+	(Groenewald *et al*., 2011;Ceccato-antonini *et al*., 2017)
Mannitol	+	+	(Groenewald *et al*., 2011;Walker, 2011)
Xylose	-	+	(Matsushika & Inoue, 2009; Limtong *et al*., 2012)

hydrolysate, but despite of these attributes, it is unable to metabolize xylose (Cunha *et al*., 2019, Ko *et al*., 2016, Lopes *et al*., 2017). Thus, by using genetic engineering approaches, potential mutant strains of *Saccharomyces* can be developed which will have the ability to ferment xylose and convert it into ethanol (Auxillos *et al*., 2019, Nevoigt, 2008). However, *Wickerhamomyces anomalus* is one such yeast having potential to metabolize both hexoses and pentoses simultaneously (Table 1).

Although in the indigenous *S. cerevisiae*, a complete metabolic pathway is present for the fermentation of xylose to produce ethanol, but this yeast is still unable to ferment xylose into ethanol completely by using xylose as a single carbon source (Van Vleet & Jeffries, 2009, Auxillos *et al*., 2019). Owning to metabolic engineering, it has now become possible to clone the genes for xylose fermentation in *S. cerevisiae* from another xylose fermenting yeast that has the ability to utilize xylose as a single carbon source. For the production of ethanol, it is important to determine the rate-limiting step in xylose consumption by *S. cerevisiae*. There are several reasons responsible for the inability of *S. cerevisiae* to use xylose as a carbon source, such as the ineffective xylose uptake, inefficient pentose phosphate pathway, reduced XK (Xylulokinase) activity, and an imbalance in the redox reactions in the first two steps of xylose metabolism. Another reason for the inefficiency of *S. cerevisiae* to use xylose is that the lower steps of glycolysis are not activated by pentose sugar metabolism due to restricted catalytic activity of non-oxidative pentose phosphate pathway enzymes. Apart from that reduced XK activity results in the formation of xylitol from xylose instead of its fermentation to ethanol (Chu & Lee, 2007, Cunha *et al*., 2019).

3 Industrial applications

3.1 *Role in food and beverages*

In different industries, specific flavor compounds are produced through fermentation process. These flavor compounds are produced from primary metabolites and the secondary metabolites. These secondary metabolites can give organoleptic characteristics to food and beverages products (Pilo *et al*., 2018, Fleet, 2007).

Many recognized yeast species are used for beneficial purposes in foods products. A novel microbe strain, *Wickerhamomyces pijperi* is used for the production of aroma from whey. Whey is the remaining liquid material that is produced after the removal of casein protein from milk. Around the world, its production per year is approximately 108 tons. Whey is used in aroma production and also in ethanol fermentation. There are many application of aroma compounds in food, cosmetics and pharmaceuticals (Izawa *et al*., 2015).

Table olives are fermented vegetable products. Fermentation technology is used for their processing in which different microorganisms such as lactic acid bacteria and yeast play a vital role to improve their quality by ensuring their safety and enhance the flavor (Bonatsou *et al*., 2017). A special strain of yeast *Wickerhamomyces anomalus* Y18 is used in the processing of the table olive. This strain has the ability to grow in harsh environmental conditions such as high salt concentration and low pH (Romero-Gil *et al*., 2013). Mostly, usage of *S. cervesae* and *W. anomala* is in fermented products. Different strains of *Saccharomyces* are used in fermentation of different foods as shown in table 2. *W. anomalus* produces some products like isoamylacetate (EAHase), acetic acid, and ethyl acetate which act as flavor enhancers in many food and beverage products (Sroka *et al*., 2014).

Table 2. Applications of *Saccharomyces* strains in food and beverage fermentation.

Saccharomyces Strains	Applications in food and beverages	References
S. pastorianus	Beer making	(Rainieri *et al*.,2006)
S. unisporus	Kefir fermentation	(Prado *et al*.,2015)
S. florentius	Kefir fermentation	(Tamang *et al*., 2016)
	Beer , Invertase	(Arumugam *et al*.,2014)
S. cerevisiae	(food additives) and wine making	(Walker *et al*.,2016)
S. sake	Sake fermentation	(Shiroma *et al*.,2014)

Table 3. Absorption capacity of yeast *genera*.

Heavy metal	Microorganism in bio-sorption	Adsorption capacity (mg/g)	References
Chromium (Cr)	*Wickerhamomyces anomalus*	28.14	(Bahafid *et al*., 2013)
Lead (Pb)	*Saccharomyces cerevisiae*	300	(Wang & Chen, 2006)
Uranium (U)	*Saccharomyces cerevisiae*	150-300	(Wang & Chen, 2006)

For the development of good aroma of cocoa beans, *S. cerevisiae* and *W. anomalus* play a vital role (Assi-Clair *et al*., 2019). Additionally, different species of *Saccharomyces* have many applications in food and beverages industry including beer making, wine making, food additives production, kefir and sake fermentation (Ciani & Comitini, 2019, Wei *et al*., 2019).

3.2 *Bio sorption of heavy metals*

Heavy metal pollution has become a global issue. Wastewater which contains heavy metal is treated with different microorganisms such as yeast, bacteria, fungi and algae. These microorganisms have the ability to uptake the metal, this phenomenon is called biosorption. It is a very cost-effective method. In this field of biotechnology, *S. cerevisiae* has caught great attention due to its distinctive metal uptake ability as compared to other fungi. Moreover, its cultivation is very easy and regarded as safe. Also, it can be modified at molecular level. As compared to other metals, Lead and uranium can be eliminated easily from diluted solutions. Lead (Pb) and Uranium (U) are adsorbed in the range of 300 and 150-300mg per gram of dry weight of metal. This bio sorption process depends upon some factors such as pH, temperature, initial concentration of biomass, initial ratio of metals and the presence of other ligands and metal ions (Nascimento *et al*., 2019).

Chromium (Cr) is found naturally in different sources such as animals, plants, rocks, volcanic dust, gas and soil but anthropogenic activities are its largest deposition source. The most dangerous and toxic type of chromium is Cr (VI), many diseases are caused by this type of chromium such as respiratory tract disorders, irritation and allergies (Sathvika *et al*., 2018, Poljsak *et al*., 2010, Lejding *et al*., 2018)

Chromium (VI) has a strong oxidizing nature. In the cell, it is reduced to chromium (III) which reacts with cell nucleic acids and other constituents of cell and cause alteration of DNA. But chromium (III) is also a constituent of micronutrients in some higher organisms, which function in the synthesis and metabolism of carbohydrates and protein stability. A special type of yeast strain known as *Wickerhamomyces anomalus* M10 has ability for its removal and conversion of Cr to non-toxic, bio-available and stable form (Fernández *et al*., 2017). Approximately 28.14mg of Cr (VI) are adsorbed by this species (Fernández *et al*., 2018, Igiehon & Babalola, 2018). Different microorganisms or yeast can adsorb different heavy metals to different extent concentration shown in table 3.

3.3 *Role as a whole-cell biocatalyst*

Recently, a strain of *Wickerhamomyces* (*W. subpelliculosus*) has been islolated which acts as a biocatalyst in whole-cell form and causes ketone bioreduction, depicted in figure 1. This type of strain is especially used for stereoselective bioreduction of prochiral ketones. *W. subpelliculosus* possesses different properties which include optimal temperature, pH and tolerance to organic solvents (Bódai *et al*., 2016).

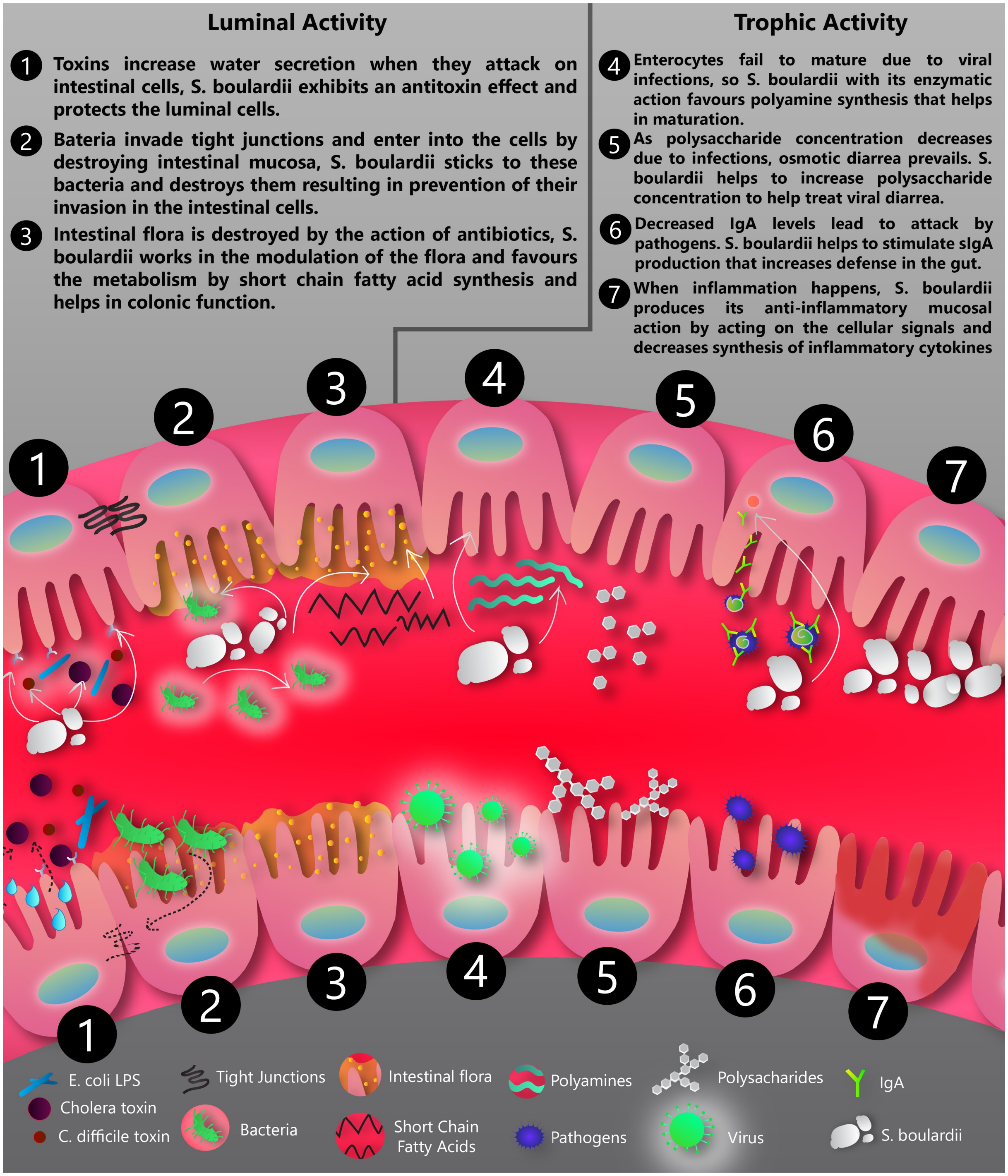

Fig. 1. General ketone bioreduction mechanism.

Orange peel provides good support for *Saccharomyces cerevisiae* cell immobilization to act as whole cell biocatalyst. This solid carrier cell immobilization is an adsorption of yeast which occurs due to covalent bonding between cell membrane and the carrier (Nedović *et al*., 2014ricc, Devanthi & Gkatzionis, 2019). As compared to free cells, immobilized cells show high activity

Table 4. *Saccharomyces* and *Wickerhamomyces* species reported to have pectinolytic activity.

Yeast	Pectinolytic activity	References
Saccharomyces cerevisiae	Yes	Gainvors *et al*., (2000) Cavalitto *et al*. (2014)
Saccharomyces boulardii	Yes	Farinazzo *et al*. (2017)
Saccharomyces fragilis	Yes	Blanco (1999)
Saccharomyces smithiae	Yes	Dasilva *et al*. (2005)
Saccharomyces fragilis	Yes	Rivera et al. (2017)
Wickerhamomyces anomalus	Yes	Martos *et al*. (2015)
Wickerhamomyces patagonicus	Yes	Garcia *et al*. (2015)

during fermentation because they are stable in a range of temperatures 15-30ºC, act with or without the addition of minerals during fermentation and efficiently convert carbohydrate substrates into volatile by-products, which have important role as food flavors. This biocatalyst property of immobilized *Saccharomyces cerevisae* cells can be effectively used in alcoholic fermentation. The purpose of cell immobilization is the production of a well-balanced alcoholic fermentation with respect to aroma, taste and overall quality (Plessas *et al*., 2007, Kyriakou *et al*., 2019).

3.4 *Pectinolytic enzyme production*

The enzymes which hydrolyse pectin containing substances are called pectinolytic enzymes. These enzymes play a vital role in food technology. They are of great importance in fruit juice and wine processing and also play vital role in maceration of plant tissue. Pectinolytic enzymes are used to breakdown the cell wall in the pulp and also used to enhance the sweating production. In the province of Misiones, a wild type yeast strain named *Wickerhamomyces anomalus* was isolated from the peels of citrus fruits, which produces pectinolytic enzymes in liquid medium, where glucose and citrus pectin act as carbon energy sources (Martos *et al*., 2013, Maidana *et al*., 2019).

Presently, microorganisms are being used for biological degradation purposes because of the increasing food waste material which is consequently leading to rise in global pollution. The yeast *Saccharomyces cerevisae* is utilized for the production of pectinase and cellulases by using only a solid potato waste source (Daskaya-Dikmen *et al*., 2018, Padma *et al*., 2011). Moreover, different species of both the genera reported to have pectinolytic activity is summarized in Table 4.

3.5 *Synergistic effect of Saccharomyces and Wickerhamomyces*

Sometimes mixed culture of *S. cerevisiae* and *Wickerhamomyces anomalus* is inoculated in wine fermentation process for quality improvement. Their combined effect produces higher level of metabolic products such as acetate, acetone, acetic acid and ethyl esters compounds that give the fruity taste to wine and increase the level of alcohol which is mainly responsible for herbaceous notes, when both the cultures were added in equal ratio, simultaneously for a period of 72 h (Ye *et al*., 2014). Canas *et al*. (2014) also reported better formation of wine using co culturing of *Saccharomyces* and *Wickerhamomyces* compared to *Saccharomyces* monoculture. This co-culturing by adding equal proportion of cultures simultaneously resulted in reduction of incubation time.

Their combined effect also reduces the concentration of organic acids and participates to enhance the aromatic quality of wine as compared to *S. cerevisiae* alone. Comparison of *Saccharomyces* and *Wickerhamomyces* genera in different applications is shown in Table 5. Recent analysis reported that the combine mixed culture usage is preferred 71.5% in red wine fermentation for better taste and fruity smell (Hu *et al*., 2018).

4 Medical applications

4.1 *Role as probiotic*

The term probiotic is used for live intestinal microflora which is beneficial to human intestine. This microflora is maintained by the addition of live microorganisms via diet. Some strains of yeast and bacteria are involved in this microflora.

Table 5. Comparison of *Saccharomyces* and *Wickerhamomyces* genera in different applications.

Scope of application	Role of *Saccharomyces*	Role of *Wickerhamomyces*	References
Second generation ethanol production	Convert hexoses into ethanol	Convert pentoses into ethanol	(Matsushika & Inoue, 2009; Limtong *et al*., 2012)
Probiotics	*S.boulardii* control of Avian coccidiosis in poultry *S. boulardii* control diarrhea	L.V-6 strain(*W. anomalus*) stimulate growth of broiler by vitamins, aminoacids, pyruvate, succinate	(Koc *et al*., 2010; Torres *et al*., 2014)
Antimicrobial activities	M12 and Cf8 killer toxins by *S. cerevisiae* used to control wine spoilage yeast. Inhibition of *Staphylococci* and *E. coli* by amine from *S. cerevisiae*	Ceramides from *W. Ciferri* act as active barrier in stratum corneum infection. Inhibition of *Botrytis cinerea*, *Aspergillus*, *Penecillum*, *Enerobacteriaceae* in fruits by *W. anomalus*. *W. anomalus* biocontrol in malaria	(de Ullivarri *et al*., 2014; Pavicic *et al*., 2007; Walker *et al*., 2011)
Food and Beverages	Beer making, kefir fermentation, Bread making, wine making, sake fermentation. Aroma compounds in cocoa beans	*W. anomalus* Y18 in processing of table olives. Production of flavour enhancer and aroma compounds. Red wine making	(Ye *et al*., 2014; Satora *et al*., 2014)
Biosorption	Heavy metals(uranium and Lead) biosorption	Heavy metal,Cr (VI) biosorption	(Wang & Chen, 2006; Fernández *et al*., 2017)
Biocatalysis	Used as biocatalysis in alcoholic fermentation	Used as biocatalyst in stereoselective bireduction of ketones	(Bodai *et al*.,2016; Plessa *et al*., 2007; Nedovic *et al*., 2015)
Enzyme production	Production of pectinolytic enzymes from Potatos waste by *S. cerevisiae*	Production of pectinolytic enzymes from peels of citrus fruits by *W. anomalus*	(Martos *et al*., 2013; Padma, *et al*.,2011)

The role of both genera as probiotics in the poultry industry as well as in the control of diarrhea has been discussed below (Sornplang & Piyadeatsoontorn, 2016; Torres *et al*., 2014).

4.1.1 In poultry industry

Recently in many countries, poultry industry has become an important economic activity. Under stressful conditions, the poultry industry has to face challenges in the form of diseases and deleterious environmental conditions that lead to great economic losses. In the recent decades, the use of veterinary medicine has been substantially increased for the control of diseases. In many cases, the utility of antimicrobial agents as a preventive measure has been addressed, given broad documentation of the advancement of antimicrobial resistance to pathogenic microscopic organisms. Farmers use probiotics as antibiotics to fill this gap (Kabir, 2009, Awais *et al*., 2019). Avian Coccidiosis is one of the most essential diseases of the poultry business. Coccidiosis brought on by Eimeria is a critical disease, responsible for the decline in growth and the death of chicken that results in the financial loss of $3 billon every year. As the poultry industry all over the world keeps on growing, so does the worry to control coccidiosis, as the expanding drug-resistance issue in the sustenance items enforces to boycott chemotherapeutic control strategies. The emergence of the drug-resistant strains of Eimeria can be prevented by administrating various drug types rotationally or by using the drugs in combination with live vaccines (Wang, Peebles, *et al*., 2018; Biswas *et al*., 2018). Thus probiotic comprises of live Pediococcus acidilactici and *Saccharomyces boulardii*. Pediococci can affect different microorganisms fundamentally through the creation of lactic acid, in addition to the production of pediocins, antimicrobial peptides by a few strains. *S. boulardii* is a powerful and safe treatment against anti-microbial related loose bowels. It also helps in the eradication of Helicobacter pylori infection (Lee *et al*., 2007; Fatoba & Adeleke, 2018). *Saccharomyces cerevisiae* is known to decrease the mortality rate and enhance the performance of broiler chicken. It is also known to induce strong immunity in the organism and to kill the pathogenic microbes present in the gut of the organisms (Wang, *et al*., 2018; García-Hernández *et al*., 2012). It happens due to adhesion competition with pathogens for target site and inactivation of salidase enzyme (Sabbatini *et al*., 2018).

LV-6 strain of yeast (*Wickerhamomyces anomalus*) has been isolated from the fattening broiler excretions and it has potentially participated as a probiotic. It also stimulates the growth of other microorganisms (Lactic acid bacteria) which are commonly used as probiotics in several organisms. Stimulation of lactic acid bacteria is achieved by the production of some vital constituents such as vitamins, amino acids, pyruvate, succinate, propionate and CO_2 by *W. anomalus* (García-Hernández *et al*., 2012, Zhou *et al*., 2018).

4.2 In control of diarrhea

The gastrointestinal (GI) microflora ('microbiota') exists together in harmony with the host. Several clinical diseases may arise at the point when this balance is disturbed. So the imbalance of microbiota has a well-established relationship with the inevitable GI illnesses. According to the latest research, there is a connection between the imbalance of microbiota and the GI diseases, such as anti-infection related looseness of the bowels (Antibiotic Associated Diarrhea), ulcers, incendiary gut illness (Inflammatory Bowel Disorder), bad tempered gut disorder (Irritable Bowel Syndrome) and colon tumour.

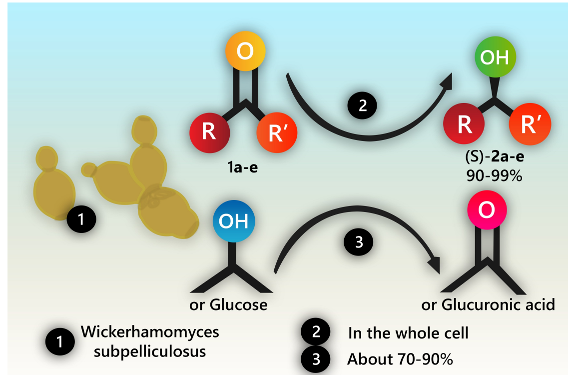

Fig. 2. Effect of *Saccharomyces boulardii* mode of action as probiotic in intestinal tract.

Endeavors have been made to enhance the wellbeing status of the influenced people by adjusting the indigenous intestinal flora, utilizing living microbial subordinates called 'probiotics' (Quraishi *et al*., 2018). *Saccharomyces boulardii* is being used as a preventive and restorative specialist for the GI problems, as it has numerous properties that make it a potential probiotic specialist as it survives through the GI tract and its optimum temperature is 37ºC both *in vitro* and *in vivo*. Furthermore, it represses the development of various microbial pathogens. The potential mechanism of action of *Saccharomyces boulardii* is depicted in figure 2. However, *S. boulardii* has a place with a gathering of basic eukaryotic cells, (for example, organisms and green growth) and along these lines, it differs from the bacterial probiotics that are prokaryotes (Ribeiro *et al*., 2018;Czeruka *et al*., 2007).

4.3 Antimicrobial characteristics

Wickerhamomyces ciferri is an asomycetous yeast, naturally produced derivatives of sphingolipids. In culture media, this unicellular organism produces an excretory product in the form of sphingoid bases. After recovery, this product is chemically modified and converted into ceramides (Schneider *et al*., 2012). Ceramides provide permeability barrier to the mammalian skin and also prevent the entry of any harmful foreign particles which have the ability to penetrate into the skin. So they provide antimicrobial and anti- inflammatory role as an active barrier in the stratum corneum infection (Pavicic *et al*., 2007).

Several different mechanisms for inhibition are used, like production of ethyl acetate, nutritional competition and direct killing mechanism by killer substances (Valzano *et al*., 2016, Ricci *et al*., 2010).

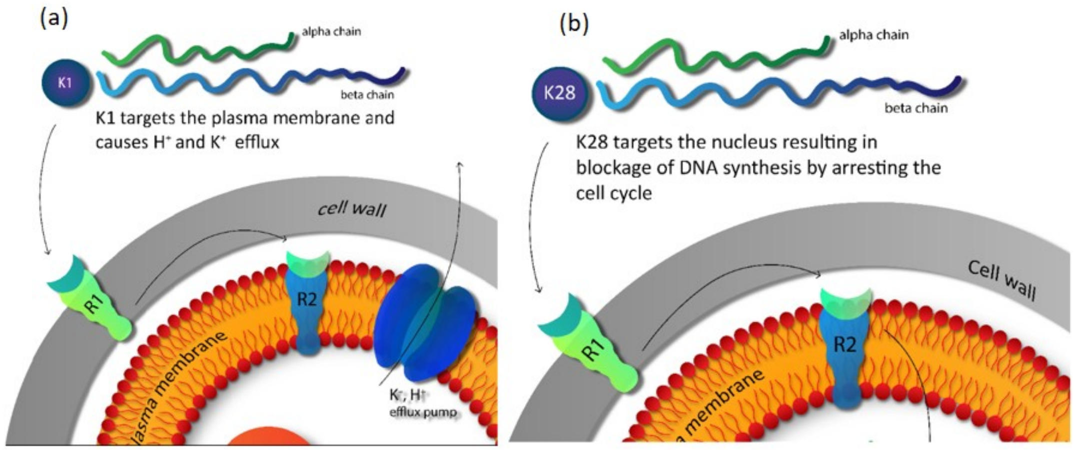

Fig. 3. Receptor mediated mode of action of K1 (a) and K28 (b) killer toxins.

Some researchers found that the antagonistic killing action of yeast against other microorganisms (yeast) involves the production of secondary metabolites known as killer toxins (KTs) called "mycocins". These killer toxins (KTs) are secreted by the self -immune killer type strains and expressed at the KTs receptors of cell wall in the form of glycoproteins with different molecular weight, variable temperature and pH range (Vrancken *et al*., 2010, Walker *et al*., 2010). This characteristic of *Wickerhamomyces anomalus* makes it valuable yeast which acts as a bio-control agent for different microorganisms. It is involved in the inhibition of *Botrytis cinereal*, *Enterobacteriaceae*, *Aspergillus* spp and *Penicillium* sp, all of which show growth on fruit stuff (Czarnecka *et al*., 2019, Haissam *et al*., 2011). Sometimes, when the baking products are stored for longer time, chances of contamination with fungus get increased. Chemicals such as benzoic, sorbic acids and propionic acids are used as preservatives but prolonged preservation with high chemical concentrations can cause many problems, like tumor developments, etc.

Scientists are working to find alternative natural methods for the antifungal activity. *Wickerhamomyces anomalus* inhibits the growth of fungus in air tight-stored cereal grains (Coda *et al*., 2011, Debonne *et al*., 2018). *W. anomalus* also shows antifungal activity against those fungi (candida sp.) which have β-1,3-glucans in their cell walls as an essential component (Izgu *et al*., 2007, Giovati *et al*., 2018).

Microbial deterioration is one of the unceasing issues in industrial fermentations responsible to cause great financial losses. In winemaking industry, this deterioration is frequently caused by the yeast belonging to the genera *Dekkera/Brettanomyces*, *Pichia*, *Zygo Saccharomyces* and *Candida*. These species are also known to cause aroma defects in wine. Likewise, diverse bacterial population is observed in wine deterioration (Golubev, 2006, Abdel-Kareem *et al*., 2019). The bacterial population is responsible to add acrolein, biogenic amines, off flavours and hydrogen peroxide in wine. In wine production, acetic acid bacteria are used as spoilage microorganisms for the oxidation of ethanol in the acetification process to produce acetic acid (Branco *et al*., 2019, de Ullivarri *et al*., 2014). Collaboration amongst microbes and yeasts has been examined by a few authors who reported bacterial control by killing yeasts in alcoholic fermentation. The inhibition character in *S. cerevisiae* was demonstrated for the first time in 1960s (Huebner *et al*., 2019, Buyuksirit & Kuleasan, 2014). *W. anomalus* is also known to produce a killer protein-panomycocin which is a strong antifungal agent (Platania *et al*., 2012). M12 and Cf8 are two killer toxins produced by *Saccharomyces cerevisiae* which are used for the bio-control of wine spoilage yeasts. Moreover, K1 and K28 killer toxins are also produced by the *Saccharomyces*. Killer yeasts are used for the reduction of contamination either during fermentation or as starter culture. During alcoholic fermentation, some antimicrobial peptides (AMPs) are produced by *Saccharomyces cerevisiae* against some wine yeast (*Hanseniaspora guilliermondii*) and bacteria (*Oenococcusoeni sp.*) which are responsible for the contamination of wine. Mostly, the AMPs are present in cationic form. By interaction with the anionic constituents of membrane, they kill the microbes as depicted in figure 3 (Branco *et al*., 2015). An amine, toxic extract from *Saccharomyces boulardii* is volatile and thermo labile in nature, and it inhibits the growth of *Staphylococcus aureus* and *Escherichia coli* (Sharma & Upadhya, 2015).

Conclusions

It was concluded that both yeasts *Saccharomyces* and *Wickerhamomyces* share similar properties in some applications like aroma production and flavour enhancement but still differs from each other in pectinolytic enzyme production, whole cell biocatalysis, biosorption, etc. with respect to target approaches and target substrates. Also, both organisms are known to possess synergistic effects in wine production. *Saccharomyces* is the most investigated eukaryote but there is still a room of research for *Wickerhamomyces*. There is much potential of *Wickerhamomyces* which is yet to be discovered in the field of bioethanol production as it can simultaneously convert pentoses and hexoses into ethanol with production of bacteriocins like compounds that will prevent the contamination issues.

References

Abdel-Kareem, M. M., Rasmey, A. M. and Zohri, A. A. (2019). The action mechanism and biocontrol potentiality of novel isolates of *Saccharomyces cerevisiae* against the aflatoxigenic *Aspergillus flavus. Letters in Applied Microbiology 68*, 104-111.

Assi-Clair, B. J., Koné, M. K., Kouame, K., Lahon, M. C., Berthiot, L., Durand, N., Lebrun, M., Julien-Ortiz, A., Maraval, I., Boulanger, R. and Guéhi, T. S. (2019). Effect of aroma potential of *Saccharomyces cerevisiae* fermentation on the volatile profile of raw cocoa and sensory attributes of chocolate produced thereof. *European Food Research and Technology*, 1-13.

Auxillos, J. Y., Garcia-Ruiz, E., Jones, S., Li, T., Jiang, S., Dai, J. and Cai, Y. (2019). Multiplex genome engineering for optimizing bio-production in *Saccharomyces cerevisiae*. *Biochemistry 58*, 1492-1500.

Awais, M. M., Jamal, M. A., Akhtar, M., Hameed, M. R., Anwar, M. I. and Ullah, M. I. (2019). Immunomodulatory and ameliorative effects of *Lactobacillus* and *Saccharomyces* based probiotics on pathological effects of eimeriasis in broilers. *Microbial Pathogenesis 126*, 101-108.

Biswas, A., Junaid, N., Kumawat, M., Qureshi, S. and Mandal, A. (2018). Influence of dietary supplementation of probiotics on intestinal histo-morphometry, blood chemistry and gut health status of broiler chickens. *South African Journal of Animal Science 48*, 968-976.

Blanco, P., Sieiro, C. and Villa, T. G. (1999). Production of pectic enzymes in yeasts. *FEMS Microbiology Letters 175*, 1-9.

Bódai, V., Nagy-Györ, L., Örkényi, R., Molnár, Z., Kohári, S., Erdélyi, B., Nagymáté, Z., Romsics, C., Paizs, C. and Poppe, L. (2016). *Wickerhamomyces subpelliculosus* as whole-cell biocatalyst for stereoselective bioreduction of ketones. *Journal of Molecular Catalysis B: Enzymatic 134*, 206-214.

Bonatsou, S., Iliopoulos, V., Mallouchos, A., Gogou, E., Oikonomopoulou, V., Krokida, M., Taoukis, P. and Panagou, E. Z. (2017). Effect of osmotic dehydration of olives as pre-fermentation treatment and partial substitution of sodium chloride by monosodium glutamate in the fermentation profile of Kalamata natural black olives. *Food Microbiology 63*, 72-83.

Branco, P., Sabir, F., Diniz, M., Carvalho, L., Albergaria, H. and Prista, C. (2019). Biocontrol of Brettanomyces/Dekkera bruxellensis in alcoholic fermentations using saccharomycin-overproducing *Saccharomyces cerevisiae* strains. *Applied Microbiology and Biotechnology 103*, 3073-3083.

Branco, P., Viana, T., Albergaria, H. and Arneborg, N. (2015). Antimicrobial peptides (AMPs) produced by *Saccharomyces cerevisiae* induce alterations in the intracellular pH, membrane permeability and culturability of *Hanseniaspora guilliermondii* cells. *International Journal of Food Microbiology 205*, 112-118.

Buyuksirit, T. and Kuleasan, H. (2014). Antimicrobial agents produced by yeasts. *International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering 8*, 1013-1016.

Canas, P. M. I., García-Romero, E., Manso, J. M. H. and Fernández-González, M. (2014). Influence of sequential inoculation of *Wickerhamomyces anomalus* and *Saccharomyces cerevisiae* in the quality of red wines. *European Food Research and Technology 239*, 279-286.

Cavalitto, S.F., Hours, R.A. and Mignone, C.F. (2014). A contribution to the characterization of protopectinase SE, an endopolygalacturonase with pectin-releasing activity from *Geotrichum klebahnii. Revista Mexicana de Ingeniería Química 13*, 75-81.

Chu, B. C. and Lee, H. (2007). Genetic improvement of *Saccharomyces cerevisiae* for xylose fermentation. *Biotechnology Advances 25*, 425-441.

Ciani, M. and Comitini, F. (2019). Use of Non-*Saccharomyces* Yeasts in Red Winemaking. In: *Red Wine Technology*, Pp. 51-68. Academic Press, USA.

Coda, R., Cassone, A., Rizzello, C. G., Nionelli, L., Cardinali, G. and Gobbetti, M. (2011). Antifungal activity of *Wickerhamomyces anomalus* and *Lactobacillus plantarum* during sourdough fermentation: Identification of novel compounds and long-term effect during storage of wheat bread. *Applied Environmental Microbiology 77*, 3484-3492.

Cunha, D. A. C., Gomes, L. S., Godoy-Santos, F., Faria-Oliveira, F., Teixeira, J. A., Sampaio, G. M. S., Trópia, M. J. M., Castro, I. M., Lucas, C. and Brandão, R. L. (2019). High-affinity transport, cyanide-resistant respiration, and ethanol production under aerobiosis underlying efficient high glycerol consumption by *Wickerhamomyces anomalus. Journal of Industrial Microbiology & Biotechnology 46*, 709-723. https://doi.org/10.1007/s10295-018-02119-5.

Cunha, J. T., Soares, P. O., Romaní, A., Thevelein, J. M. and Domingues, L. (2019). Xylose fermentation efficiency of industrial *Saccharomyces cerevisiae* yeast with separate or combined xylose reductase/xylitol dehydrogenase and xylose isomerase pathways. *Biotechnology for Biofuels 12*, 20.

Czarnecka, M., Żarowska, B., Polomska, X., Restuccia, C. and Cirvilleri, G. (2019). Role of biocontrol yeasts *Debaryomyces hansenii* and *Wickerhamomyces anomalus* in plants' defence mechanisms against *Monilinia fructicola* in apple fruits. *Food Microbiology 83*, 1-8.

Czeruka, D., Piche, T. and Rampal, P. (2007). Yeast as probiotics-*Saccharomyces boulardii. Alimentary Pharmacology & Therapeutics 26*, 767-778.

Daniel, H. M., Moons, M. C., Huret, S., Vrancken, G. and De Vuyst, L. (2010). *Wickerhamomyces anomalus* in the sourdough microbial ecosystem. *Antoine van Leeuwenhoek 99*, 63-73.

Dasilva, E., Borjes, M., Medina, C., Piccoli, R., and Schwan, R. (2005). Pectinolytic enzymes secreted by yeasts from tropical fruits. *FEMS Yeast Research 5*, 859-865.

Daskaya-Dikmen, C., Karbancioglu-Guler, F. and Ozcelik, B. (2018). Cold active pectinase, amylase and protease production by yeast isolates obtained from environmental samples. *Extremophiles 22*, 599-606.

Debonne, E., Van Bockstaele, F., Van Driessche, M., De Leyn, I., Eeckhout, M. and Devlieghere, F. (2018). Impact of par-baking and packaging on the microbial quality of par-baked wheat and sourdough bread. *Food Control 91*, 12-19.

Devanthi, P. V. P. and Gkatzionis, K. (2019). Soy sauce fermentation: Microorganisms, aroma formation, and process modification. *Food Research International 120*, 364-374.

Farinazzo, F. S., Farinazzo, E. S., Spinosa, W. A., and Garcia, S. (2017). *Saccharomyces boulardii*: Optimization of simultaneous saccharification and fermentation of cell production in organic and conventional apple substrate pulp. *Food Science and Biotechnology 26*, 969-977.

Fatoba, A. J. and Adeleke, M. A. (2018). Diagnosis and control of chicken coccidiosis: a recent update. *Journal of Parasitic Diseases 42*, 483-493.

Fernández, P. M., Cruz, E. L., Viñarta, S. C. and Castellanos de Figueroa, L. I. (2016). Optimization of culture conditions for growth associated with Cr (VI) removal by *Wickerhamomyces anomalus* M10. *Bulletin of Environmental Contamination and Toxicology 98*, 400-406.

Fernández, P. M., Viñarta, S. C., Bernal, A. R., Cruz, E. L. and Figueroa, L. I. (2018). Bioremediation strategies for chromium removal: Current research, scale-up approach and future perspectives. *Chemosphere 208*, 139-148.

Fleet, G. H. (2007). Yeasts in foods and beverages: impact on product quality and safety. *Current Opinion in Biotechnology 18*, 170-175.

Gainvors, A., Nedjaoum, N., Gognies, S., Muzart, M., Nedjma, M. and Belarbi, A. (2000). Purification and characterization of acidic endo-polygalacturonase encoded by the PGL1-1gene from *Saccharomyces cerevisiae. FEMS Microbiology Letters 183*, 131-135.

García-Hernández, Y., Rodríguez, Z., Brandão, L. R., Rosa, C. A., Nicoli, J. R., Elías Iglesias, A., Peréz-Sanchez, T., Salabarría, R. B. and Halaihel, N. (2012). Identification and *in vitro* screening of avian yeasts for use as probiotic. *Research in Veterinary Science 93*, 798-802.

Giovati, L., Santinoli, C., Ferrari, E., Ciociola, T., Martin, E., Bandi, C., Ricci, I., Epis, S. and Conti, S. (2018). Candidacidal Activity of a Novel Killer Toxin from *Wickerhamomyces anomalus* against fluconazole-susceptible and -resistant strains. *Toxins 10*, 68.

Golubev, W. I. (2006). *Biodiversity and Ecophysiology of Yeasts* (ed. by G. Péter and C. Rosa. Berlin), Pp 197-219 Springer Berlin Heidelberg.

Ha, S.J., Galazka, J. M., Rin Kim, S., Choi, J.H., Yang, X., Seo, J.H., Louise Glass, N., Cate, J. H. D. and Jin, Y.S. (2010). Engineered *Saccharomyces cerevisiae* capable of simultaneous cellobiose and xylose fermentation. *Proceedings of the National Academy of Sciences 108*, 504-509.

Haissam, J. M. (2011). *Pichia anomala* in biocontrol for apples: 20 years of fundamental research and practical applications. *Antoine van Leeuwenhoek 99*, 93-105.

Hossain, A. H., Tobola, F., Sedee, N., Punt, P. J., Havekes, M. and Zha, Y. (2013). *Pichia anomala* 29X: a resistant strain for lignocellulosic biomass hydrolysate fermentation. *FEMS Yeast Research 13*, 609-617.

Hu, K., Jin, G.J., Mei, W.C., Li, T. and Tao, Y.S. (2018). Increase of medium-chain fatty acid ethyl ester content in mixed *H. uvarum*/*S. cerevisiae* fermentation leads to wine fruity aroma enhancement. *Food Chemistry 239*, 495-501.

Huebner, K. L., Martin, J. N., Weissend, C. J., Holzer, K. L., Parker, J. K., Lakin, S. M., Doster, E., Weinroth, M. D., Abdo, Z., Woerner, D. R., Metcalf, J. L., Geornaras, I., Bryant, T. C., Morley, P. S. and Belk, K. E. (2019). Effects of a *Saccharomyces cerevisiae* fermentation product on liver abscesses, fecal microbiome, and resistome in feedlot cattle raised without antibiotics. *Scientific Reports 9*, 2559.

Igiehon, N. O. and Babalola, O. O. (2018). Fungal bio-sorption potential of chromium in Norkrans liquid medium by shake flask technique. *Journal of Basic Microbiology 59*, 62-73.

Izawa, N., Kudo, M., Nakamura, Y., Mizukoshi, H., Kitada, T. and Sone, T. (2015). Production of aroma compounds from whey using *Wickerhamomyces pijperi. AMB Express 5*, 23.

Izgu, F., Altinbay, D. and Türeli, A. E. (2007). *In vitro* susceptibilities of *Candida sp*. to panomycocin, a novel exo-β-1,3-glucanase isolated from *Pichia anomala* NCYC 434. *Microbiology and Immunology 51*, 797-803.

Jansen, T., Hoff, J. W., Jolly, N. and Van zyl, W. H. (2017). Mating of natural *Saccharomyces cerevisiae* strains for improved glucose fermentation and lignocellulosic inhibitor tolerance. *Folia Microbiologica 63*, 155-168.

Jönsson, L. J., Alriksson, B. and Nilvebrant, N.O. (2013). Bioconversion of lignocellulose: inhibitors and detoxification. *Biotechnology for Biofuels 6*, 16.

Kabir, S. M. L. (2009). The role of probiotics in the poultry industry. *International Journal of Molecular Sciences 10*, 3531-3546.

Ko, J. K., Um, Y., Woo, H. M., Kim, K. H. and Lee, S.M. (2016). Ethanol production from lignocellulosic hydrolysates using engineered *Saccharomyces cerevisiae* harboring xylose isomerase-based pathway. *Bioresource Technology 209*, 290-296.

Kyriakou, M., Chatziiona, V. K., Costa, C. N., Kallis, M., Koutsokeras, L., Constantinides, G. and Koutinas, M. (2019). Biowaste-based biochar: A new strategy for fermentative bioethanol overproduction via whole-cell immobilization. *Applied Energy 242*, 480-491.

Lee, S., Lillehoj, H. S., Park, D. W., Hong, Y. H. & Lin, J. J. (2007). Effects of Pediococcus- and *Saccharomyces*-based probiotic (MitoMax®) on coccidiosis in broiler chickens. *Comparative Immunology, Microbiology and Infectious Diseases 30*, 261-268.

Lejding, T., Mowitz, M., Isaksson, M., Bruze, M., Pontén, A., Svedman, C., Zimerson, E. and Engfeldt, M. (2018). A retrospective investigation of hexavalent chromium allergy in southern Sweden. *Contact Dermatitis 78*, 386-392.

Li, X., Chen, Y. and Nielsen, J. (2019). Harnessing xylose pathways for biofuels production. *Current Opinion in Biotechnology 57*, 56-65.

Limtong, S., Nitiyon, S., Kaewwichian, R., Jindamorakot, S., Am-In, S. and Yongmanitchai, W. (2012). *Wickerhamomyces xylosica* sp. nov. and Candida phayaonensis sp. nov., two xylose-assimilating yeast species from soil. *International Journal of Systematic and Evolutionary Microbiology 62*, 2786-2792.

Lopes, D. D., Rosa, C. A., Hector, R. E., Dien, B. S., Mertens, J. A. and Ayub, M. A. Z. (2017). Influence of genetic background of engineered xylose-fermenting industrial *Saccharomyces cerevisiae* strains for ethanol production from lignocellulosic hydrolysates. *Journal of Industrial Microbiology & Biotechnology 44*, 1575-1588.

Lorenzini, M., Simonato, B. and Zapparoli, G. (2018). Yeast species diversity in apple juice for cider production evidenced by culture-based method. *Folia Microbiologica 63*, 677-684.

Madrigal, T., Maicas, S. and Mateo Tolosa, J. J. (2012). Glucose and ethanol tolerant enzymes produced by *Pichia* (*Wickerhamomyces*) isolates from enological ecosystems. *American Journal of Enology and Viticulture 64*, 126-133.

Maidana, S. A., Butiuk, A. P., Zubreski, E. R., Hours, R. A., Brumovsky, L. A. and Martos, M. A. (2019). Production of an endopolygalacturonase from *Wickerhamomyces anomalus* with disintegration activity on plant tissues. *Biocatalysis and Agricultural Biotechnology 18*, art. no. 101042. https://doi.org/10.1016/j.bcab.2019.101042.

Martos, M. A., Butiuk, A. P., Rojas, N. L., and Hours, R. A. (2014). Purification and characterization of a polygalacturonase produced by *Wickerhamomyces anomalus*. *Brazilian Archives of Biology and Technology 57*, 587-594.

Martos, M., Zubreski, E. R., Garro, O. A. and Hours, R. A. (2013). Production of pectinolytic enzymes by the yeast *Wickerhanomyces anomalus* isolated from citrus fruits peels. *Biotechnology Research International 2013*, 7.

Moysés, D. N., Reis, V. C. B., Almeida, J. R. M. d., Moraes, L. M. P. d. and Torres, F. A. G. (2016). Xylose fermentation by *Saccharomyces cerevisiae*: Challenges and prospects. *International Journal of Molecular Sciences 17*, 207.

Nascimento, D. J. M., de Oliveira, J. D., Rizzo, A. C. L. and Leite, S. G. F. (2019). Biosorption Cu (II) by the yeast *Saccharomyces cerevisiae*. *Biotechnology Reports 21*, https://doi.org/10.1016/j.btre.2019.e00315

Nedović, V., Gibson, B., Mantzouridou, T. F., Bugarski, B., Djordjević, V., Kalušević, A., Paraskevopoulou, A., Sandell, M., Šmogrovičová, D. and Yilmaztekin, M. (2014). Aroma formation by immobilized yeast cells in fermentation processes. *Yeast 32*, 173-216.

Nevoigt, E. (2008). Progress in Metabolic Engineering of *Saccharomyces cerevisiae*. *Microbiology and Molecular Biology Reviews 72*, 379-412.

Padma, N. P., Anuradha, K. and Reddy, G. (2011). Pectinolytic yeast isolates for cold-active polygalacturonase production. *Innovative Food Science & Emerging Technologies 12*, 178-181.

Pavicic, T., Wollenweber, U., Farwick, M. and Korting, H. C. (2007). Anti-microbial and -inflammatory activity and efficacy of phytosphingosine: an *in vitro* and *in vivo* study addressing acne vulgaris. *International Journal of Cosmetic Science 29*, 181-190.

Pérez, C. R., Medina-Moreno, S. A., Martínez, A., Lizardi-Jiménez, M.A., Espinosa-Solares, T. and Téllez-Jurado. A. (2018). Effect of concentration of salts in ethanol production from acid hydrolysis of cladodes of *Opunia ficus indica* VAR. ATLIXCO. *Revista Mexicana de Ingeniería Química 17*, 349-364.

Piló, F. B., Carvajal-Barriga, E. J., Guamán-Burneo, M. C., Portero-Barahona, P., Dias, A. M. M., Freitas, L. F. D. d., Gomes, F. d. C. O. and Rosa, C. A. (2018). *Saccharomyces cerevisiae* populations and other yeasts associated with indigenous beers (chicha) of Ecuador. *Brazilian Journal of Microbiology 49*, 808-815.

Platania, C., Restuccia, C., Muccilli, S. and Cirvilleri, G. (2012). Efficacy of killer yeasts in the biological control of *Penicillium digitatum* on Tarocco orange fruits (*Citrus sinensis*). *Food Microbiology 30*, 219-225.

Plessas, S., Bekatorou, A., Koutinas, A. A., Soupioni, M., Banat, I. M. and Marchant, R. (2007). Use of *Saccharomyces cerevisiae* cells immobilized on orange peel as biocatalyst for alcoholic fermentation. *Bioresource Technology 98*, 860-865.

Poljsak, B., Pócsi, I., Raspor, P. and Pesti, M. (2010). Interference of chromium with biological systems in yeasts and fungi: a review. *Journal of Basic Microbiology 50*, 21-36.

Quraishi, F., Fatima, G., Shaheen, S., Memon, Z., Kainat, S. and Agha, F. (2018). *In vitro* comparison of antimicrobial actions of probiotics *Lactobacilli* species and *Saccharomyces boulardii* with standard antibiotics for the treatment of Diarrhea in pediatric population. *International Journal of Clinical Medicine 9*, 827-840.

Ribeiro, M., Oliveira, D., Oliveira, F., Caliari, M., Martins, F., Nicoli, J., Torres, M., Andrade, M., Cardoso, V. and Gomes, M. (2018). Effect of probiotic *Saccharomyces boulardii* in experimental giardiasis. *Beneficial Microbes 9*, 789-797.

Ricci, I., Mosca, M., Valzano, M., Damiani, C., Scuppa, P., Rossi, P., Crotti, E., Cappelli, A., Ulissi, U., Capone, A., Esposito, F., Alma, A., Mandrioli, M., Sacchi, L., Bandi, C., Daffonchio, D. and Favia, G. (2010). Different mosquito species host *Wickerhamomyces anomalus* (*Pichia anomala*): perspectives on vector-borne diseases symbiotic control. *Antonie van Leeuwenhoek 99*, 43-50.

Rivera N. A., Cruz-Guerrero, A.E., Morales-Estrada, A.I., Gómez-Ruiz, L., López-Perez, M. and García-Garibay, M. (2017). Endopolygalacturonase from *Kluyveromyces marxianus* CDBB-L-278: A comparative study of gene expression and enzyme activity under aerobic and anaerobic conditions *Revista Mexicana de Ingeniería Química 16*, 399-404.

Robnett, C. J., Basehoar-Powers, E. and Kurtzman, C. P. (2008). Phylogenetic relationships among species of *Pichia*, *Issatchenkia* and *Williopsis* determined from multigene sequence analysis, and the proposal of Barnettozymagen. nov. Lindneragen. nov. and *Wickerhamomyces* gen. nov. *FEMS Yeast Research 8*, 939-954.

Romero-Gil, V., Bautista-Gallego, J., Rodríguez-Gómez, F., García-García, P., Jiménez-Díaz, R., Garrido-Fernández, A. and Arroyo-López, F. N. (2013). Evaluating the individual effects of temperature and salt on table olive related microorganisms. *Food Microbiology 33*, 178-184.

Sabbatini, S., Monari, C., Ballet, N., Mosci, P., Decherf, A.C., Pélerin, F., Perito, S., Scarpelli, P. and Vecchiarelli, A. (2018). *Saccharomyces cerevisiae* based probiotic as novel anti-microbial agent for therapy of bacterial vaginosis. *Virulence 9*, 954-966.

Sathvika, T., Soni, A., Sharma, K., Praneeth, M., Mudaliyar, M., Rajesh, V. and Rajesh, N. (2018). Potential application of *Saccharomyces cerevisiae* and Rhizobium immobilized in multi walled carbon nanotubes to adsorb hexavalent chromium. *Scientific Reports 8*, 9862.

Schneider, J., Andrea, H., Blom, J., Jaenicke, S., Rückert, C., Schorsch, C., Szczepanowski, R., Farwick, M., Goesmann, A., Pühler, A., Schaffer, S., Tauch, A., Köhler, T. and Brinkrolf, K. (2012). Draft Genome Sequence of *Wickerhamomyces ciferri*i NRRL Y-1031 F-60-10. *Eukaryotic Cell 11*, 1582-1583.

Shao, Y., Lu, N., Wu, Z., Cai, C., Wang, S., Zhang, L.-L., Zhou, F., Xiao, S., Liu, L., Zeng, X., Zheng, H., Yang, C., Zhao, Z., Zhao, G., Zhou, J.-Q., Xue, X. and Qin, Z. (2018). Creating a functional single-chromosome yeast. *Nature 560*, 331-335.

Sornplang, P. and Piyadeatsoontorn, S. (2016). Probiotic isolates from unconventional sources: a review. *Journal of Animal Science and Technology 58*, 26.

Sroka, P., Tarko, T., Blaszczyk, U. and Satora, P. (2014). The influence of *Wickerhamomyces anomalus* killer yeast on the fermentation and chemical composition of apple wines. *FEMS Yeast Research 14*, 729-740.

Torres, V., Albelo, N., Febles, M. and Noda, A. C. (2014). Probiotic effect of a strain of *Wickerhamomyces anomalus* on fattening broilers. *Cuban Journal of Agricultural Science 2014 48*, 125-128.

Ullivarri, D. M. F., Mendoza, L. M. and Raya, R. R. (2014). Killer activity of *Saccharomyces cerevisiae* strains: partial characterization and strategies to improve the biocontrol efficacy in winemaking. *Antonie van Leeuwenhoek 106*, 865-878.

Valzano, M., Cecarini, V., Cappelli, A., Capone, A., Bozic, J., Cuccioloni, M., Epis, S., Petrelli, D., Angeletti, M., Eleuteri, A. M., Favia, G. and Ricci, I. (2016). A yeast strain associated to Anopheles mosquitoes produces a toxin able to kill malaria parasites. *Malaria Journal 15*, 21.

Van Vleet, J. H. and Jeffries, T. W. (2009). Yeast metabolic engineering for hemicellulosic ethanol production. *Current Opinion in Biotechnology 20*, 300-306.

Virginia, D.G., Libkind, D, Moliné, M, Rosa, C.A. and Giraudo, M.R. (2014). Cold-adapted yeasts in Patagonian habitats. In: *Cold-adapted Yeasts*, Pp123-148. Springer, Berlin, Heidelberg.

Vrancken, G., De Vuyst, L., Van der Meulen, R., Huys, G., Vandamme, P. and Daniel, H.M. (2010). Yeast species composition differs between artisan bakery and spontaneous laboratory sourdoughs. *FEMS Yeast Research 10*, 471-481.

Walker, G. M. (2010). Pichia anomala: cell physiology and biotechnology relative to other yeasts. *Antoine van Leeuwenhoek 99*, 25-34.

Wang, J., Wang, Y., Liu, Z., Liu, N. and Wang, J. (2018). Effect of supplemental yeast cell walls on growth performance, gut mucosal glutathione pathway, proteolytic enzymes and transporters in growing broiler chickens. *Journal of Animal Science 96*, 1330-1337.

Wang, X., Peebles, E. D., Kiess, A. S., Wamsley, K. G. and Zhai, W. (2018). Effects of *Bacillus subtilis* and zinc on the growth performance, internal organ development, and intestinal morphology of male broilers with or without subclinical coccidia challenge. *Poultry Science 97*, 3947-3956.

Wei, J., Wang, S., Zhang, Y., Yuan, Y. and Yue, T. (2019). Characterization and screening of non-*Saccharomyces* yeasts used to produce fragrant cider. *LWT Food Science and Technology 107*, 191-198.

Wild, R., Kowal, J., Eyring, J., Ngwa, E. M., Aebi, M. and Locher, K. P. (2018). Cryo-EM structure of the yeast oligosaccharyl transferase (OST) complex. *Science 359*, 545.

Ye, M., Yuan, Y. and Yue, T. (2014). Microbial diversity in traditional type I sourdough and jiaozi and its influence on volatiles in Chinese steamed bread. *LWT Food Science and Technology 101*, 764-773.

Zhou, J. J., Peng, L. J., Liu, Q., Peng, S. Y., Zhang, X., Hu, X. Q., Wang, X. D. and Hu, J. P. (2018). Identification and characterization of probiotic yeast isolated from digestive tract of ducks. *Poultry Science 97*, 2902-2908.