Importance of Yeasts and Lactic Acid Bacteria in Food Processing

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1 Introduction

Yeasts are non-photosynthetic, relatively sophisticated, living, unicellular fungi. They are substantially beneficial to human culture, in particular for the production of alcoholic beverages and foods. Yeasts also play detrimental role in the spoilage of foods and beverages and some can be pathogenic. Of the yeasts, *Saccharomyces cerevisiae* and related species are widely used in the food and beverage industries. Many species of *Saccharomyces* are safe (GRAS) and the term "yeast" is generally employed as synonymous with *Saccharomyces cerevisiae* (Stewart and Russell 1998). In industry, yeasts are commercially used in the production of alcoholic beverages, industrial alcohols, baker's yeast, enzymes and yeast-derived flavour products (Walker 1999).

Lactic acid bacteria are unicellular prokaryotes of Gram-positive, non-sporing, non-respiring cocci or rods which form lactic acid as the major end-product during the fermentation of sugars. Lactic acid bacteria include the species of *Lactobacillus*, *Carnobacterium*, *Leuconostoc*, *Oenococcus*, *Streptococcus*, *Lactococcus*, *Enterococcus*, *Vagococcus*, *Pediococcus*, *Aerococcus* and *Tetragenococcus*

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(Bourdichon et al. 2012). Many lactic acid bacteria are safe and they are used extensively in the production and maturation of fermented foods and beverages such as yoghurt, pickles, table olives, sour dough bread (Axelsson 1998; Caplice and Fitzgerald 1999).

This chapter will briefly discuss the beneficial aspects of yeasts and lactic acid bacteria in food processing.

2 Yeasts in Food Processing

2.1 Baker's Yeast and Single-Cell Production

Baker's yeast, *Saccharomyces cerevisiae*, is used for bakery and confectionary processes throughout the world (Akbaria et al. 2012; Romano and Capece 2013).

Baker's yeast can be found in different forms like compressed, granular, cream, dried pellet, instant, encapsulated or frozen (Young and Cauvain 2007).

Some of the basic desired properties of baker's yeast are rapidly utilization of maltose, tolerance to high levels of sucrose, enduring freeze-thawing stress and production of high levels of CO_2. Another desired feature of baker's yeast is using disaccharide melibiose. One of the most desirable characteristic of baker's yeast strains is high fermentation rate. Development of the freeze-tolerance and freeze-thawing survival of yeasts is a property that could be useful for the quality and generation of bakery products. Baker's yeast should be osmotolerant, able to tolerate chemicals (salt, propionates), maintain a high growth capacity, should not aggregate and must have a good storage capability. In addition, during the drying process and after the addition of dry yeast to flour for dough making, the yeast must have a high rate of vitality (Randez-Gil et al. 1999).

High fermentation rate is priority desired for baker's yeast strains since it is completely connected to dough-leavening. Yeasts at the same time encourage gluten network and generate aromatic compounds (Romano and Capece 2013). During the fermentation, *Saccharomyces cerevisiae* metabolises fermentable sugars (glucose, sucrose, maltose and fructose) and results in releasing CO_2 therefore rising dough volume. CO_2 is soluble in water and saturates the aqueous phase. After reaching saturation, all CO_2 produced passes through unsaturated gas phase and permit rising of the volume of bread. Solubilization of CO_2 in water results in decreasing the pH and elevates the acidity of the dough (Boekhout and Robert 2003). In addition, CO_2 affects rheological characteristics of fermented dough (Romano and Capece 2013). The most important two factors for volume of the bread are fermentation activity of yeast (producing CO_2) and ability of the dough to keep gas. The second one is carried out by gluten network. Accordingly these two components have to be in balance to acquire a quality end-product (Boekhout and Robert 2003).

Yeast contributes to the bakery products not only for increasing volume of the dough, but also producing aroma compounds (Birch et al. 2013). Due to the activity

of yeasts, aroma compounds are formed widely in the crumb of bread and the most abundant compounds are alcohols, aldehydes as well as 2,3-butanedione (diacetyl), 3-hydroxy-2-butanone (acetoin) and esters (Hazelwood et al. 2008).

Volatile compounds which are responsible for aroma properties of dough and aroma precursors are produced by the thermal reactions during baking. In the course of the dough fermentation performed by yeasts, the chemical phenomena that dominates the fermentation is alcohol fermentation (Pozo et al. 2006).

Single-cell proteins are normally mentioned as source of mixed proteins. They are obtained from microorganisms like algae, fungi, yeasts and bacteria. If microbial cells are composed of significant amount of proteins, these microorganisms are referred as single-cell protein and native protein source. Due to increasing human population and the worldwide shortage of protein microbial biomass as food and feed, single-cell protein has gained importance (Nasseri et al. 2011).

Yeasts are the most suitable microorganisms for the production of single-cell proteins due to their high nutritional value. Some of the yeasts for production of single-cell proteins are *Candida lipolytica, Saccharomyces cerevisiae, Amoco torula, Candida utilis, Candida intermedia* and *Candida tropicalis* (Chandrani and Jayathilake 2000).

2.2 Production of Alcoholic Beverages

Yeasts play an important role in the production of fermented alcoholic beverages, especially beer, wine and distilled spirits. *Saccharomyces cerevisiae* is the most important species involved in wine making and brewing (McKay et al. 2011). Fermentation is the core microbial reaction in the production of alcoholic beverages and the microorganisms, which contaminate the raw materials before and after fermentation, can affect the final quality of fermented products. For the quality assurance of alcoholic beverages, controlling of such influences has become an important issue (Fleet 1998).

2.2.1 Beer

Beer is made from starch containing malted cereals, notably barley, hops, water and yeasts. Beer processing is a multistage process and fermentation is one of these stages (Deak 2008). In the brewery fermentation yeasts convert the fermentable sugars (mainly maltose) in the wort to ethanol and carbon dioxide as the major products of metabolism. Also a series of minor metabolites such as esters, higher alcohols, organic acids, aldehydes, ketones, sulphur compounds those contribute to flavour and aroma of beer are produced by yeasts (Briggs et al. 2004; Gibson et al. 2008). Depending on these minor metabolites, yeasts have a fundamental impact on the quality since these compounds play a key role on the organoleptic profile of beer (Pinho et al. 2006; Ferreira et al. 2010).

Brewer's yeast belongs to the group of *Saccharomyces sensu stricto* formed around the species *Saccharomyces cerevisiae* and is mainly divided into two groups, ale brewing yeasts and lager brewing yeasts, according to their use for the production of ales and lagers, respectively (Deak 2008; Lodolo et al. 2008; Nakao et al. 2009). These brewer's yeasts are classified based on flocculation behaviour; top fermenting and bottom fermenting which are called as *Saccharomyces cerevisiae* (ale type) and *Saccharomyces cerevisiae* (lager type) in the literature, respectively (Stewart and Russell 1998; Jentsch 2007). However, in beverage industry, ale yeast is referred as *Saccharomyces cerevisiae* and lager yeast is referred as *Saccharomyces uvarum* (*carlsbergensis*). Currently, yeast taxonomists have assigned all strains used in brewing to the species *Saccharomyces cerevisiae* (Stewart and Russell 1998). Top-fermenting yeasts produce ale beers at fermentation temperatures above 15 °C. At the end of fermentation they are carried to the surface of the wort. The other type is lager beer which is the most widespread beer type throughout the world. Lager beers are produced by bottom fermenting yeasts at fermentation temperatures below 15 °C. Lager yeasts have a good flocculation ability. They form flocculates at the bottom of the vessel by clumping together (Bamforth 2003; Ferreira et al. 2010). Top yeasts and bottom yeasts are collected to be used again from the surface and the fermenter bottom, respectively (Stewart and Russell 1998; Campbell 2003). Moreover, ale and lager yeasts are also different from each other depending on the ability to ferment the disaccharide melibiose (glucose-galactose). Since lager yeasts have the MEL gene, they can produce the extracellular enzyme α-galactosidase (melibiase) and are able to utilise melibiose. On the other hand, ale yeasts do not have the MEL gene, consequently do not produce α-galactosidase, therefore unable to utilise melibiose (Stewart and Russell 1998; Lodolo et al. 2008).

Brewing yeast should produce desirable flavour and aroma metabolites for the final product and fast growth, rapid and efficient fermentation are other essential properties (Campbell 2003). The brewing yeast should tolerate the environmental stresses, such as high ethanol and low oxygen levels (Ferreira et al. 2010). Ethanol is a desirable product of the fermentation process, but accumulation of it can cause significant chemical stress on the yeast cell (Lentini et al. 2003; Hutkins 2006). Suitable flocculation and sedimentation or head formation at the end of the fermentation are other essential requirements depending on the beer type. High final viability for pitching for the next fermentation and high genetic stability are other important properties of suitable brewing yeast (Campbell 2003).

2.2.2 Wine

Yeasts are important microorganisms in wine microbiology. Biotransformation of grape sugars into ethanol, carbon dioxide and several secondary products is a complex process and yeasts are responsible for this conversion (Ciani et al. 2010). Besides the conversion of sugars to ethanol, yeasts also make positive contributions to wine flavour by the synthesis of other minor metabolites that define the flavour and other sensorial properties (Cortes and Blanco 2011; De Benedictis et al. 2011; Navarrete-Bolanos 2012). The main activities of wine yeasts are rapid, complete and

efficient conversion of the grape sugars into ethanol and carbondioxide; influencing the quality of the grapes before the harvest by biocontrol of molds; biocatalysis of neutral grape components into flavour active compounds; producing secondary metabolites such as esters, acids, alcohols, aldehydes, ketones, polyols, volatile sulphur compounds which directly impact the wine flavour without development of off-flavours (Lambrechts and Pretorius 2000; Fleet 2003a). Spontaneous fermentation of "must" is initiated by indigenous yeasts and final stages are dominated by the alcohol-tolerant strains of *Saccharomyces cerevisiae*. The non-Saccharomyces yeasts, commonly *Kloeckera* spp. and *Candida* spp., dominate at the beginning of the fermentation and affect the sensorial characteristics of wine (Ganga and Martinez 2004). The other isolated yeasts are *Metschnikowia, Dekkera, Pichia, Kluyveromyces, Issatchenkia, Saccharomycodes, Zygosaccharomyces, Torulaspora, Debaryomyces,* and *Schizosaccharomyces* (Fleet 2003a). It was reported that *Kloeckera apiculata* (its telemorph *Hanseniaspora uvarum*) is the predominant non-*Saccharomyces* yeast present in grape must (Fleet and Heard 1993). When the ethanol content starts to increase during the fermentation, *Saccharomyces cerevisiae,* the main wine yeast, degrades the sugar and can tolerate high ethyl alcohol. It takes over the fermentation and completes the process (Fleet and Heard 1993; Blanco et al. 2012).

Fast fermentation of grape juice sugars to high ethanol concentrations is essential for wine yeasts. Wine yeasts should exhibit uniform dispersion and produce minimal foam. At the end of the fermentation, sediment should be quickly taken from the wine. It is also important that the yeast should not give slow, sluggish or stuck fermentations (Bisson 1999). Desirable characteristics of wine yeasts include some properties such as rapid initiation of fermentation, high fermentation efficiency, high ethanol tolerance, high osmotolerance, moderate biomass, high genetic stability, high sulphite tolerance, low sulphite binding activity, low foam formation, compacts sediment, resistance to desiccation, killer activity, genetic marking, proteolytic activity and low nitrogen demand. Other properties which are related to the flavour characteristics are also reported as low volatile acidity production, less higher alcohol production, liberation of glycosylated flavour precursors, high glycerol production, hydrolytic activity, enhanced autolysis and modified esterase activity. Moreover, the yeast must give a good flavour, free of sensory faults, and allow the grape character to be perceived by the consumer (Lambrechts and Pretorius 2000; Swiegers et al. 2005; Ciani et al. 2010). Low sulphite and biogenic amine formation and low ethyl carbamate (urea) potential are metabolic properties related to health implications (Pretorius 2000; Curtin et al. 2011).

2.3 Yeasts in Table Olives

Table olive is an important fermented product in the food industry. Depending on some of its unique characteristics such as the bitter component called oleuropein, low sugar concentration and high oil content, it cannot be consumed directly and needs to be processed (Arroyo-López et al. 2008). During the processing of table olives, microorganisms, both lactic acid bacteria and yeasts, play important roles.

Yeasts act as both desirable and spoilage microorganisms in table olives (Garrido-Fernández et al. 1997; Arroyo-López et al. 2012). It was reported that the species of yeast mainly present in the table olive fermentation are in the genera of *Saccharomyces, Pichia*, *Debaryomyces, Candida* and *Kluyveromyces* (Arroyo-López et al. 2008; Tofalo et al. 2013). Yeasts produce compounds such as alcohols, ethyl acetate, acetaldehyde and organic acids which enhance the organoleptic characteristics (Garrido-Fernandez et al. 1995; Arroyo-López et al. 2008; Alves et al. 2012). Moreover, yeasts in olive fermentation could improve the aromatic profile of fermented olives by increasing their free fatty acid content, which could be the precursors to the formation of diverse volatile compounds, such as propanol or 2-butanol (Hernández et al. 2007; Rodriguez-Gómez et al. 2010; Rodríguez-Gómez et al. 2012). Another positive effect of yeasts on the olive fermentation is acting as biocontrol agents which are achieved by the toxic proteins also called as killer toxins those enable the inhibition of the growth of fungi (Viljoen 2006; Arroyo-López et al. 2012). It was reported that a considerable number of killer strains of *Debaryomyces, Pichia* and *Candida* species were isolated from table olives (Marquina et al. 1997). Especially, inhibitory activities of species *Wickerhamomyces anomalus* and *Pichia membranaefaciens* were proven against the fungi (Santos et al. 2000; Arroyo-López et al. 2012). Moreover, yeasts can improve growth of lactic acid bacteria which are the essential organisms of fermentation by the synthesis of nutritive compounds (Viljoen 2006; Alves et al. 2012; Tofalo et al. 2013).

Nevertheless, yeasts sometimes may be associated with different kinds of olive spoilage such as gas pocket formation depending on the production of CO_2, softening of the fruits due to pectinolitic activity, clouding of brines, biofilm production and sometimes production of off-flavours (Arroyo-López et al. 2008; Alves et al. 2012).

2.4 Yeasts in Meat-Based Fermented Foods

Yeasts are found on meat and processed meat products since meat is a suitable media for growth of them. They have also positive effects on fermented meat products and many yeast species such as *Candida, Debaryomyces, Pichia, Trichosporon, Cryptococcus, Rhodotorula* and *Yarrowia* have been isolated from fermented meat products, especially sausages (Dillon and Board 1991; Deak 2008). Lipolytic and proteolytic activities, which contribute to flavour due to the production of volatiles, of those yeasts were described (Olesen and Stahnke 2000; Selgas and Garcia 2007). Most frequently isolated yeasts are *Yarrowia lipolytica* and *Debaryomyces hansenii* (its anamorph *Candida famata*) (Gardini et al. 2001; Deak 2004). *Debaryomyces hansenii* is also used as commercial starter culture in fermented meat products due to its positive contributions on final product (Hammes and Hertel 1998; Toldrá 2002; Selgas and Garcia 2007).

2.5 Yeasts in Dairy-Based Fermented Foods

Various types of yeasts are naturally found in milk and fermented dairy products such as kefir, koumis, viili, longfil, yoghurt and all types of cheese (Wouters et al. 2002; Frölich-Wyder 2003; Cantor et al. 2004). Yeasts play essential role due to their important functions in dairy based products such as contributing to the ripening of cheese, speeding up the maturation, improving texture and aroma characteristics of certain milk products, increasing pH of cheese, manufacturing of some metabolites like ethanol, acetaldehyde, CO_2, amino acids and vitamins, removing toxic end-products of metabolism, taking part in some interactions and contributing to the fermentation by supporting the starter cultures, preventing some undesired microorganisms those cause product quality default, inducing the growing of starter cultures by means of the utilization of organic acids, contributing to the flavour characteristic of dairy products due to the strong proteolytic and lipolytic activity, fermenting lactose and utilizing citric acid (Fleet 1990; Spinnler et al. 2001; Jakobsen et al. 2002; Ferreira and Viljoen 2003).

Most common yeast species found in dairy products are as follows: *Candida lusitaniae, Candida krusei*, *Kluveromyces lactis, Debaryomyces hansenii, Yarrowia lipolytica, Kluyveromyces marxianus*, *Saccharomyces cerevisiae*, *Galactomyces geotrichum*, *Candida zeylanoides* and various *Pichia* species. These yeast species play a key role in the processing of dairy-based fermented products by the contribution to flavour and colour (Jakobsen and Narwnjs 1996; Viljoen 2001; Samelis and Sofos 2003; Jacques and Caserogola 2008).

There are numerous studies to identify yeast species in various cheese types. *Debaryomyces hansenii, Candida lipolytica, Candida kefyr, Candida intermedia, Saccharomyces cerevisiae, Cryptococcus albidus* and *Kluyveromyces marxianus* are the most prevelant species in Camembert and Blue-veined cheese (Roostita and Fleet 1996), *Debaryomyces hansenii, Galactomyces candidum, Issatchenkia orientalis, Kluyveromyces lactis, Kluyveromyces marxianus, Saccharomyces cerevisiae, Yarrowia lipolytica* and *Candida catenulata* were identified as predominant yeast species in various cheeses from Austria, Denmark, France, Germany and Italy (Prillinger et al. 1999). Additionally, *Saccharomyces unisporus* and *Kluyveromyces marxianus* are utilised for the manufacture of kefir (Abdelgadir et al. 2001; Gadaga et al. 2001; Strehaiano et al. 2006).

Especially, *Debaryomyces hansenii* and *Yarrowia lipolytica* are suitable for generation of starter cultures because of their proteolytic and lipolytic activity and also make favorable contributions on cheese ripening (Van den Tempel and Jacobsen 2000; Guerzoni et al. 2001; Ferreira and Viljoen 2003). In a study on feta cheeses, various aroma compounds were investigated and it was shown that yeast species are effective in the formation of aromatic substances such as 2,3-bütandiol (McSweeney and Sousa 2000), 1-bütanol, 1-heptanol, hexanal and nonanal (Bintsis and Robinson 2004; Kesenkaş and Akbulut 2006).

2.6 Yeasts in Cereal-Based Fermented Foods

Cereal and cereal crops are accepted as significant nutrients all over the world. Cereal grains and legumes are utilised as raw material for many foods and beverages in different countries and cultures (Blandino et al. 2003; Heredia et al. 2009). The basic cereals utilised for nourishment are corn (maize), wheat, barley, rice, oats, rye, millet, sorghum and soybeans. Cereals are substrates for some fermentation products such as; beer, sake, spirits, boza, fura, malt vinegar, tarhana, idli and baked goods made from doughs leavened by yeasts or sourdough. Cereal based foods are usually performed by natural fermentations including mixed cultures of yeasts, bacteria and fungi (Gotcheva et al. 2000; Hammes et al. 2005; Settani et al. 2011).

Sourdough is a significant product for bakeries and it is characterized as combined activity of yeasts and lactic acid bacteria (Giannou et al. 2003; Chavan and Jana 2008). The most important function of yeasts in sourdough fermentation is metabolizing fermentable sugars for generating CO_2, increasing gas formation capacity, improving flavour and aroma, contributing to the texture of the crumb and the nutritional value (De Vuyst and Vancanneyt 2007; Vogelmann et al. 2009; Vrancken et al. 2010; Chavan and Chavan 2011). The generated CO_2 plays an important role in the formation of dough volume and is used for leavening agent and affects bread texture, density and volume (Decock and Cappelle 2005).

2.7 Bioethanol Production (Industrial Ethyl Alcohol)

The importance of biofuels continues to increase worldwide. Alternative energy sources are necessary for all over the world because of political instability of oil producer countries, global environmental concerns, volatile oil price and negative effects of fosil fuels (Wyman 2007; Bai et al. 2008; Mussatto et al. 2010). Bioethanol is commonly thought as the most promising biofuels among renewable sources (Sanchez and Cardona 2008; Moona et al. 2012).

Bioethanol can be produced from various raw materials. Wide variety of renewable feedstock can be classified in three main groups: (1) simple sugars those containing significant amounts of easily fermentable sugar (sugar cane, sugar beets, sweet sorghum), (2) starches and fructosans (corn, potatoes, rice, wheat, agave, inulin) and (3) cellulosics (stover, grasses, corn cobs, wood, sugar cane bagasse) (Demirbas 2007; Sanchez and Cardona 2008; Amorim et al. 2009; Chi et al. 2011).

Yeasts for bioethanol fermentation can be defined in terms of their performance parameters such as temperature range, pH range, alcohol tolerance, growth rate, productivity, osmotic tolerance, specificity, yield, genetic stability and inhibitor tolerance (Dien et al. 2003). Conventially, *Saccharomyces cerevisiae* is used for bioethanol fermentation. *Saccharomyces cerevisiae* can ferment glucose into bioethanol, but unable to ferment xylose (Keshwani and Cheng 2009). Xylose-fermenting yeasts, such as *Pichia stipitis, Candida shehatae* and *Candida parapsilosis*, can metabolise xylose via the action of xylose reductase and xylitol

dehydrogenase. Hereby, using recombinant *Saccharomyces cerevisiae*, carrying heterologous xylitol reductase and xylitol dehydrogenase from *Pichia stipitis* and xylulokinase from *Saccharomyces cerevisiae*, bioethanol production from xylose can be successfully done (Katahira et al. 2006).

2.8 Yeast-Derived Products

A reliable source of ingredients and additives for food processing is obtained from yeasts (Demain et al. 1998). Preparations of baker's and brewer's yeasts have been available for many years as dieatary supplements due to their high content of proteins, peptides, amino acids, B vitamins and trace minerals. At the present time, numerous products are derived from yeasts which are antioxidants, autolysates, enzymes, minerals, vitamins, colour and flavour compounds (Stam et al. 1998).

Yeasts and yeast extracts are known as source of antioxidant compounds for years (Abbas 2006). It is believed that yeast peroxisomes play nearly the same role to plant peroxisomes. Consequently, the response in yeasts to oxygen-derived radicals would include various enzymes, involving catalases, superoxide dismutases and glutathione, besides several NADP-dependent dehydrogenases (Del Rio et al. 2003).

Interest to the biotechnological generation of natural aroma compounds is rapidly increasing. Yeasts contribute significantly to the aroma of fermented foods. During fermentation yeasts synthesize a vast number of aroma compounds (Suomalainen and Lehtonen 1979; Berry 1995). The numerically and quantitatively largest groups of aroma compounds synthesized by yeasts consist of fusel alcohols, fatty acids, acids, esters, carbonyl compounds, acetals, phenols, hydrocarbons, nitrogen compounds, sulphur compounds, lactones, sugars, and a diversity of other unclassified compounds (Suomalainen and Lehtonen 1978, 1979; Berry 1989, 1995; Garafolo 1992; Dickinson 2003).

Yeast-formed flavours can be generally classified into three categories as yeast metabolic products which include products synthesized or derived through yeast biocatalysis, yeast cell mass-derived products which include products prepared through yeast autolysis and complex products resulting from the interaction of yeast-derived products with other food matrix ingredients (Kollar et al. 1992; Stam et al. 1998).

Yeast extracts can be produced using autolysis, plasmolysis and hydrolysis but the most frequently production practise is autolysis (Tanguler and Erten 2008). They are concentrates of the soluble fraction of yeast cells and mainly produced from baker's or spent brewer's yeasts, both *Saccharomyces cerevisiae*. In Europe, the main raw material for yeast extract is baker's yeast which is primary grown high protein yeast. In the UK and the USA, debittered brewer's yeast is used. Other yeasts, in particular, *Candida utilis* and *Kluyveromyces marxianus* are also sometimes used (Sommer 1998). Recently, temperature-sensitive autolysing strain of *Saccharomyces cerevisiae* which showed increased autolysis at 37 °C has been used for yeast extract by Asahi Breweries in Japan (Stam et al. 1998).

To produce a product by autolysis, viable yeast slurry containing 15–20 % yeast solids is maintained at an elevated temperature in the range of 45–60 °C for up to 36 h or more at about pH 5.5 (Nagodawithana 1992; Joseph 1999). At elevated temperatures, the yeast cells die but their native enzymes are still remain active (Sommer 1998). During autolysis, intracellular yeast enzymes located in the general matrix of the cell cause breakdown of mainly proteins, peptides, carbohydrates, nucleic acids (mainly RNA) and cell wall materials into free amino acids (mainly glutamate), peptides, sugars and nucleotides (Stam et al. 1998). The most important flavour enhancing components are glutamate and 5′-nucleotides, especially 5′-guanylate (5′-GMP). Glutamate has 100–300 mg/l of taste threshold, for 5′-inosinate (5′-IMP) and 5′-guanylate 120 and 35 mg/l, respectively. Glutamate and 5′-nucleotides are chemically stable substances but enzimatically active foods such as raw meats, raw fish and vegetable tissues can degrade these compounds (Sommer 1998).

Plasmolysis is generally used for rapid initiation of the cell degradation process for the production of yeast extract especially in Europe but less popular in the USA. During plasmolysis, yeast cells start to lose water to equilibrate their osmotic pressure with the surrounding medium in the presence of high amounts of promoters (Nagodawithana 1992, 1994).

Commonly used plasmolysing agents are common salt (sodium chloride), sucrose, ethanol, ethyl acetate, amyl acetate, chloroform, toluene and combinations of salts such as potassium chloride (Peppler 1982). The most frequently utilised agent is common salt (Reed and Nagodawithana 1991) at the ratio of 1–3 %. However, using salt as a plasmolysing agent leads to an extract with high salt concentration (Reed and Nagodawithana 1991; Nagodawithana 1994).

Yeast cells are also rich source of vitamins such as thiamine, pantothenic acid, riboflavin, vitamin B6, and vitamin B12 (Harrison 1970; Peppler 1970; Reed 1981; Halasz and Laszity 1991). Yeast cells are also good sources of biotin, folic acid and ergosterol.

Intracellular yeast enzymes can be prepared from whole yeast cell mass by mechanical disruption and other means. These enzymes have found several food uses (Peppler 1979; Reed 1981; Halasz and Laszity 1991). Invertase obtained from *Saccharomyces cerevisiae* and other sucrolytic food yeasts are used in the confectionary industry to break down sucrose for manufacturing liquid-centre candies (Reed 1981; Halasz and Laszity 1991). Lactase from *Kluyveromyces* spp. is also important for several food uses, especially to hydrolyse lactose. Ribonuclease obtained from baker's yeast is used for RNA denaturation during the manufacture of yeast nucleotides (Sanchez et al. 2003).

A number of yeasts can produce carotenoids which are used as food colorants including species of *Rhodotorula* (*Rhodotorula glutinis*, *Rhodotorula lactis*, *Rhodotorula gracilis*, *and Rhodotorula rubra*), *Rhodosporidium*, *Phaffia rhodozyma* and *Sporobolomyces pararoseus* (Cang et al. 2002; Squina et al. 2002; Simova et al. 2003; Frengova et al. 2003, 2004; Cheng et al. 2004).

2.9 Yeasts as Biocontrol Agents

There is a good relationship between the terms of sustainable agriculture and biocontrol, because biological control concept benefits from natural biological cycles with the minimal environmental effect in the field of crop production (Spadaro and Gullino 2004). All foods and beverages have a wide variety of microbial species and interactive responses which affect the product quality. The major underlying response in biocontrol concept is antagonistic interactions (Fleet 2006). Antogonism effect is the inhibition of undesired or pathogenic microorganisms by competition for space or nutrients via the manufacture of toxic materials and by providing environmental exchange and by production of antimicrobial metabolites thus survival of desirable species (Huber 1997; Fleet 2006; Pometto et al. 2006; Satyanarayana and Kunze 2009).

Biocontrol activity of antagonism could be increased using many applications such as combining organic and inorganic additives with antogonistic yeasts (Mecteau et al. 2002). The most interesting microorganisms in biological control programmes are yeasts. Because they have some important properties which make them reasonable to be used as biocontrol agents (Satyanarayana and Kunze 2009).

In the last 20 years, some yeasts which can be utilised as potential biocontrol agent were identified. Some fungi such as *Botrytis*, *Penicillium*, *Aspergillus*, *Rhizopus* spp. give rise to pre and postharvest spoilage of fruits and vegetables. Certain yeasts can be used as biocontrol agents to these spoilage microorganisms and therefore chemicals can be less frequently used (Punja and Utkhede 2003; Fleet 2003b; Spadaro and Gullino 2004). Some of prominent potential biocontrol yeasts have been commercialised; e.g. *Candida oleophila* and *Pseudozyma flocculosa.* Some of the other species which are used as potential biocontrol agents are determined as *Metschnikowia pulcherrima*, *Pichia guilliermondii*, *Candida sake*, *Sporobolomyces roseus*, *Aureobasidium pullulans* and various *Cryptococcus* species (Fleet 2003b).

2.10 Probiotic Yeasts

Although lactic acid bacteria are well-known probiotic organisms, some yeast species also recognised as probiotics due to their health benefits. *Saccharomyces cerevisiae* var. *boulardii* and *Saccharomyces cerevisiae,* have been reported as the major probiotic yeasts. Moreover, there is an interest to some other non-*Saccharomyces* species such as *Debaryomyces hansenii, Yarrowia lipolytica, Issatchenkia orientalis, Kluyveromyces marxianus* and *Kluyveromyces lactis* to be used as probiotics (Fleet 2006; Fleet and Balia 2006).

3 Lactic Acid Bacteria in Food Processing

3.1 Plant-Based Fermented Products

Plant-based fermented foods are popular all over the world and consumer demand for these fermented products is increasing. Olives, cucumber and sauerkraut are commercially important plant-based fermented vegetables eventhough most vegetables are fermented at small-scale level.

3.1.1 Table Olives

Table olives are one of the most important fermented foods obtained by mainly the action of lactic acid bacteria. The main processing types are lye-treated green olives in brine, untreated black olives in brine and ripe olives. First two methods include the lactic acid fermentation (Harris 1998; Hurtado et al. 2012).

Lactobacillus plantarum and *Lactobacillus pentosus* are the predominant species in most of the fermentations. However, the other lactobacilli or genera can take partial responsibility for this essential role or even can be the major actor of the fermentations depending on the olive cultivar, processing method and the geographical origin (Hurtado et al. 2012). Both of them are suitable for fermenting various table olive cultivars (Sánchez et al. 2001; Panagou et al. 2008) but cultivar and processing method are the major actors of a successful inoculation (Panagou and Tassou 2006; Hurtado et al. 2010).

In order to achieve an enhanced and more predictable fermentation process, brine inoculation with an appropriate starter culture of lactic acid bacteria can be used. Lactic acid bacteria convert carbohydrates into lactic acid, CO_2 and other organic acids without the need for oxygen in the medium. However, higher concentrations of phenolic compounds in olive fruit, mainly oleuropein, could inhibit lactic acid bacteria (Amiot et al. 1990; Sánchez-Gómez et al. 2006; Landete et al. 2008; Hurtado et al. 2009; Rodriguez et al. 2009; Ghabbour et al. 2011). Moreover these phenolic compounds, especially oleuropein, give bitterness, therefore they are removed from fruit to become edible by the treatment with sodium hydroxide for lye-treated Spanish style green olives production. Unlike alkali treatment, to hydrolyse the bitter-tasting oleuropein, *Lactobacillus pentosus* can be used as starter due to its glycosidases and esterase activities (Servili et al. 2006).

Starters can be chosen based on a large variety of criteria like homo- and heterofermentation, acid production, salt tolerance, flavour development, temperature range, oleuropein-splitting ability and bacteriocin-production (Ruiz-Barba and Jimenez-Diaz 1995; Durán Quintana et al. 1999; Delgado et al. 2005).

Olives' fermentation is done by the natural biota of olives consisting of a variety of bacteria, yeasts, and molds. The lactic acid bacteria become prominent during the intermediate stage of fermentation. Initially *Leuconostoc mesenteroides* and

Pediococcus cerevisiae (now called *Pediococcus pentosaceus*) become prominent, and then lactobacilli, with *Lactobacillus plantarum* and *Lactobacillus brevis* become the most important.

Growth of *Lactobacillus plantarum* in the fermentation provides the necessary lactic acid formation for preservation and also for its characteristic flavour (Rodriguez De Le Borbolla et al. 1979, 1981). Also using suitable *Lactobacillus plantarum* starter cultures potentially improve the microbiological control of the process, increase the lactic acid yield and highly qualified fermented green olives are produced (Fernandez Diez 1983; Roig and Hernandez 1991; Ruiz-Barba et al. 1991; Garrido-Fernandez et al. 1995; Ruiz-Barba and Jimenez-Diaz 1995). Lactic acid bacteria can form the flavour during the fermentation. Numerous volatile compounds make a significant contribution to the final flavour of table olives (Sabatini et al. 2008).

3.1.2 Pickled Vegetables

Cucumber

Cucumbers are typically fermented in brine solutions in large tanks. Lactic acid bacteria may be involved during the primary fermentation of cucumbers. *Lactobacillus plantarum* and *Pediococcus pentosaceus* have been chosen as the desired species of lactic acid bacteria for commercial cucumber fermentations. These homofermantative species are preferred for the fermentation to minimize purging requirements to remove CO_2. Cucumber sugars are converted into lactic acid by the fermentation which is carried out by primarily *Lactobacillus plantarum* and pH is decreased (Ic and Ozcelik 1995, 1999).

During brine fermentation, keeping the structure integrity of whole cucumbers is very important. As a result of respiration and malolactic fermentation by *Lactobacillus plantarum*, CO_2 may be formed. In order to prevent the serious economic losses due to gaseous spoilage (bloater damage), cucumbers may be purged with air. It should be taken into consideration that such kind of practice may increase the risk of growth of molds and yeasts (Tamang et al. 2005).

The potential involvement of *Lactobacillus buchneri* is indicated in the study of spoilage of fermented cucumber (Fleming et al. 1989, 2002; Kim and Breidt 2007). *Lactobacillus buchneri* has been isolated from fermented cucumbers those had undergone spoilage, characterized by decreased concentrations of lactic acid, increased pH, and increased concentrations of acetic and propionic acids (Franco and Pérez-Díaz 2012; Johanningsmeier et al. 2012). Only *Lactobacillus buchneri* was found to initiate lactic acid utilization in fermented cucumber media after several lactic acid bacteria have been isolated from spoiled fermented cucumber (Johanningsmeier et al. 2012). Therefore, *Lactobacillus buchneri* plays the major role in the initiation of secondary fermentations which lead to spoilage of fermented cucumber.

Sauerkraut

Sauerkraut is a commonly consumed vegetable in some European countries. It is a fermentation product of fresh cabbage. The starter for sauerkraut production is generally the normal flora of cabbage. *Leuconostoc mesenteroides* and *Lactobacillus plantarum* are the two most preferred lactic acid bacteria in sauerkraut fermentation. As well as *Lactobacillus plantarum*, *Lactobacillus brevis* also affects the final stages of sauerkraut production (Kalac et al. 1999).

Sauerkraut production is generally based on a sequential microbial process that involves heterofermentative and homofermentative lactic acid bacteria. In this process *Leuconostoc* species and *Lactobacillus*, *Pediococcus* species involve as the first and second group, respectively (Font De Valdez et al. 1990). *Leuconostoc* primarily uses glucose and fructose for its growth and produce lactic and acetic acids, ethanol, mannitol and CO_2 (Aukrust et al. 1994). These bacteria slow down and begin to die off, when the acidity reaches to 0.25–0.3 % as lactic acid. The activity started by *Leuconostoc mesenteroides* is continued by *Lactobacillus plantarum* and *Lactobacillus cucumeris* until an acidity level of 1.5–2 % as lactic acid is reached. Finally, *Lactobacillus pentoaceticus* continues the fermentation and the acidity reaches to 2–2.5 %, so completes the fermentation.

The end-products of a normal sauerkraut fermentation are mainly lactic acid, smaller amounts of acetic and propionic acids, a mixture of gases of principally carbon dioxide, small amounts of alcohol and a mixture of aromatic esters. However the acidity helps to control the growth of spoilage and undesired microorganisms.

3.2 Sour-Dough Breads

The dough properties (Collar 1996), organoleptic characteristics (Hammes et al. 1996), nutritional value (Lopez et al. 2001) and the shelf life of bread (Lavermicocca et al. 2000) are improved by lactic acid bacteria in bread making.

Sourdough is prepared with flour and water, containing a wide variety of lactic acid bacteria (Gobbetti 1998; Hammes and Gaenzle 1998). High numbers of lactic acid bacteria found in cereal sourdoughs, including mainly *Lactobacillus, Leuconostoc* and *Lactococcus* species (Hounhouigan et al. 1993; Johansson et al. 1995). It is reported that the dominant *Lactobacillus* species in wheat sourdoughs are *Lactobacillus sanfranciscensis* (which is reported as identical to *Lactobacillus brevis* var. *lindneri*) (Hutkins 2006)*, Lactobacillus brevis, Lactobacillus fermentum* and *Lactobacillus fructivorans* (Gobbetti et al. 1994; Corsetti et al. 2001, 2003). Some described species such as *Lactobacillus plantarum*, *Lactobacillus alimentarius, Lactobacillus acidophilus*, *Lactobacillus delbrueckii* subsp. *delbrueckii* (Gobbetti et al. 1994; Corsetti et al. 2001, 2003)*, Lactobacillus spicheri* (Meroth et al. 2003), *Lactobacillus mindensis* (Ehrmann et al. 2003), *Lactobacillus frumenti* (Müller et al. 2000) and *Lactobacillus paralimentarius* (Cai et al. 1999) were also isolated from sourdough. In this complex system, the synthesis of bacteriocins and

other antimicrobial compounds could regulate the interactions between the starter and the contaminant microflora of the sourdough (Corsetti et al. 2004).

The performance of lactic acid bacteria strains in the food matrix has been studied by characterization of the acidification parameters and lactic and acetic acid production during sourdough fermentation (Hammes and Gaenzle 1998). The organic acids would also contribute to the production of aroma compounds (Meignen et al. 2001).

In sourdoughs, the sugar usage by lactic acid bacteria strains is related to the microorganism, the type of sugar, the presence of yeasts, and the manufacturing conditions (Hammes and Gaenzle 1998; Martinez-Anaya 2003). On the whole, *Lactobacillus reuteri* strains, which were isolated from homemade doughs, ferment different sugars, e.g., sucrose, melibiose, rafinose, fructose, while most *Lactobacillus sanfranciscensis* strains only ferment maltose (Corsetti et al. 2001).

3.3 Lactic Acid Bacteria and Wine

Lactic acid bacteria are responsible for malolactic fermentation (MLF) in wines which can be beneficial in some cases and undesirable in the others (Krieger 1993).

Primary importance of lactic acid bacteria in wine making is malolactic fermentation. The main malolactic fermentation reaction is the decarboxylation of L-malic acid to L-lactic acid. In this reaction the acidity decreases and pH raises by 0.3–0.5 units. The malolactic fermentation is done both by Lactobacilli and Leuconostoc.

Malolactic bacteria growing in wine must be capable of tolerate low nutrient concentration, low pH and high concentrations of ethanol and SO_2. When wines involve residual glucose and fructose, there is undesirable acidification.

Malolactic fermentation could be conducted by the species of *Lactobacillus* or *Pediococcus,* but this reaction usually results in non-acceptable wines when pH is higher than 3.5. These genera usually can not tolerate low pH and produce undesirable flavours along with high levels of acetic acid (Murphy et al. 1985; Krieger et al. 1990).

To conduct malolactic fermentation, *Oenococcus oeni* (formerly *Leuconostoc oenos*) is primarily preferred bacterial species, rather than yeast or other lactic acid bacteria. *Oenococcus oeni* is especially adapted to the harsh environment of wine and is capable of converting malic acid to lactic acid quickly. Hence different strains of *Oenococcus oeni* can have particularly different effects on the final product, and some strains are more beneficial to the properties of wine than others (Henick-Kling 2002).

3.4 Lactic Acid Bacteria in Fermented Dairy Products

Especially mesophilic *Lactococcus lactis* and thermophilic *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus* are important lactic acid bacteria in the process of dairy products; for example, yogurt, cheese and buttermilk. By lactic acid fermentation, acetaldehyde and diacetyl production increase

and this causes flavour formation in yogurt and buttermilk. Lactic acid bacteria also produce exopolysaccharides which help to increase structural properties of fermented dairy products. In addition, one of the health benefits of dairy products is the conversion of lactose and galactose to the sweetener such as L-alanine (Hugenholtz et al. 2000).

Lactococcus lactis, especially sub-species of *lactis* and *cremoris* are the commonly used starter bacteria for some cheese types (Gouda and Cheddar cheese), butter and buttermilk. This bacterium can grow in milk easily and converts lactose to lactic acid. With a nitrogen source in medium, it hydrolyses casein. This biochemical process occurs during ripening of cheese and it helps to form flavour by the result of amino acid release. Other important characteristic of *Lactococcus lactis* in some strains is that they can convert citric acid to diacetyl (flavour of butter) and CO_2 (Hugenholtz 1993).

Streptococcus thermophilus is another lactic acid bacteria used in dairy fermentation as starter culture especially in yogurt. It is also used for some cheeses such as Swiss (Emmenthaler) and Italian (Parmesan) types. Its growing temperature is 40–45 °C. Special characteristic of this bacterium is that, it metabolises only the glucose-moiety from lactose and residual galactose is exerted from cell. *Streptococcus thermophilus* forms only L (+) lactate. During milk fermentation of *Streptococcus thermophilus*, a flavour compound, acetaldehyde is also produced (Caplice and Fitzgerald 1999; Hugenholtz et al. 2000).

Lactobacillus delbrueckii subsp. *bulgaricus* is used together with *Streptococcus thermophilus* for the production of yoghurt. It is homofermantative yoghurt bacterium with growing temperature of 40–45 °C. *Lactobacillus delbrueckii* subsp. *bulgaricus* produce D (-) lactic acid. Although lactic acid is the main end-product of yoghurt fermentation, flavour compounds such as acetaldehyde, acetone, diacetyl (2,3-bütanedione) and acetoin can also be formed in very low amounts (Caplice and Fitzgerald 1999; Chaves et al. 1999).

Lactobacillus acidophilus as obligate homofermantative, is a probiotic lactic acid bacterium. Hexose sugars are metabolised primarily to lactic acid. It is used for the production of acidophilus in milk mixed culture with *Lactobacillus delbrueckii* subsp. *bulgaricus.*

Lactic acid bacteria contribute to the structural characteristic of the fermented dairy products by the production of exopolysaccharides. Especially in yoghurt and in some Scandinavian dairy products, for example viili and longfil, both *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* produce these sugar polymers (Van Kranenburg et al. 1999).

3.5 Lactic Acid Bacteria in Meat Products

Lactic acid bacteria help meat products to protect them from pathogenic microorganism and improve their sensory quality during fermentation. Increasing acidification leads to prevent development of spoilage and pathogenic activities. It also contributes to stabilization of colour and texture. Lactic acid bacteria can produce

bacteriocins which help to preserve fresh and processed meat (Kröckel 2013). The predominant lactic acid bacteria during lactic acid fermentation of sausages are *Lactobacillus sakei* and *Lactobacillus curvatusare*. However, some species of *Lactobacillus* spp. and *Pediococcus* spp. are used as starter cultures for most European fermented sausages formulated with nitrite (Caplice and Fitzgerald 1999).

3.6 Lactic Acid Bacteria in Traditional Turkish Fermented Foods and Beverages

3.6.1 Tarhana

Tarhana, a traditional cereal-based lactic acid fermented food product, is widely consumed in Turkey and Middle East. Tarhana is obtained primarily by mixing yoghurt, wheat flour, yeast, salt, depending on the region raw or cooked vegetables (tomato, onion, pepper, etc.) and spices (mint, basil, dill, tarhana herb, etc.). Fermentation is usually carried out by yoghurt bacteria and fermentation lasts for 1–7 days (Ibanoglu and Ibanoglu 1998). *Lactobacillus delbrueckii* subsp. *bulgaricus*, *Streptococcus thermophilus, Lactobacillus fermentum, Pediococcus acidilactici, Lactobacillus plantarum, Lactobacillus brevis, Enterococcus faecium, Pediococcus pentosaceus, Leuconostoc pseudomesenteroides* and *Weissella cibaria* are identified in tarhana fermentations (Sengun et al. 2009; Settani et al. 2011).

The resulting product is listed among the acidic fermented foods characterised by sour taste and strong yeast flavour (Ibanoglu and Ibanoglu 1999; Sagdic et al. 2002; Dağlioğlu et al. 2002; Sengun et al. 2009).

The dominant microbiota of tarhana is mainly lactic acid bacteria and yeasts. Lactic acid bacteria are the most important microbial group for tarhana fermentation. They play the main role in the production of aromatic compounds those are typical for the final product (Settani et al. 2011). Also, they increase acidity and control the mechanism to enhance the safety (Settanni and Corsetti 2008).

3.6.2 Boza

Boza is a mildly alcoholic beverage produced from the fermentation of barley, oats, millet, maize, wheat or rice. It is a traditional Turkish-fermented beverage. *Lactobacillus acidophilus, Lactobacillus brevis, Lactobacillus coprophilus, Lactobacillus coryniformis, Lactobacillus fermentum, Lactobacillus paracasei, Lactobacillus pentosus, Lactobacillus plantarum, Lactobacillus rhamnosus, Lactobacillus sanfrancisco, Lactococcus lactis* subsp. *lactis, Leuconostoc mesenteroides, Leuconostoc mesenteroides* subsp. *dextranicum, Leuconostoc raffinolactis, Pediococcus pentosaceus, Oenococcus oeni*, *Weissella confusa* and *Weissella paramesenteriodes* were found in boza samples (Arici and Daglioglu 2002; Todorov and Dicks 2006). Only a few papers reported the isolation of yeasts and moulds from boza. It was reported that boza is a good source of bacteriocin-producing lactic acid bacteria (Todorov and Dicks 2006).

3.6.3 Kefir

Kefir is an acidic and low-alcoholic fermented dairy product with its functional properties (Farnworth 1999, 2006; Farnworth and Mainville 2003). Traditionally, the people of the Caucasus prepared the kefir by fermenting milk in tulum made from fur of animals (Yaygin 1995).

Kefir differs from other fermented dairy products, because "kefir grains" have a complex microflora include heterofermentative and homofermentative lactic acid bacteria, acetic acid bacteria and yeasts (Marshall et al. 1984; Toba et al. 1987; Piodux et al. 1990). Manufacturing a quality kefir beverage with stable starter culture is difficult because type of microorganisms and their ratio differ from the origin of "kefir grains" and there are different opinions for the type of microorganisms in "kefir grains" (Yaygin 1995).

The main producer of kefiran polymer in kefir grains is *Lactobacillus kefiranofaciens* and other species of lactobacilli (Frengova et al. 2002; Irigoyen et al. 2005). Lactic acid bacteria present in kefir grains or kefir products were isolated and identified, including *Lactobacillus acidophilus* (Angulo et al. 1993), *Lactobacillus brevis* (Simova et al. 2002), *Lactobacillus paracasei* subsp. *paracasei* (Simova et al. 2002), *Lactobacillus delbrueckii* (Simova et al. 2002; Witthuhn et al. 2004), *Lactobacillus helveticus* (Angulo et al. 1993; Lin et al. 1999; Simova et al. 2002), *Lactobacillus kefiri* (Angulo et al. 1993; Takizawa et al. 1998; Garrote et al. 2001), *Lactobacillus kefiranofaciens* (Takizawa et al. 1998), *Lactobacillus plantarum* (Garrote et al. 2001), *Leuconostoc mesenteroides* (Lin et al. 1999; Garrote et al. 2001; Witthuhn et al. 2004), *Lactococcus lactis* (Garrote et al. 2001; Simova et al. 2002; Witthuhn et al. 2004), *Streptococcus thermophilus* (Simova et al. 2002).

3.6.4 Shalgam

Shalgam, a traditional Turkish lactic acid fermented beverage, is mainly produced in some provinces of Southern Turkey (Tangüler and Erten 2012a). The raw materials used for shalgam production are black carrot, turnip, rock-salt, sourdough, bulgur flour and drinkable water. It is a red coloured, cloudy and sour non-alcoholic drink (Erten et al. 2008).

Lactic acid bacteria are the main fermentation agents of shalgam and they are responsible for the acidification process by converting sugars into mainly lactic acid and other end compounds which give the typical taste and flavour to the shalgam (Erten et al. 2008).

There is limited information about the microflora of shalgam and its microbiology is complex. *Lactobacillus plantarum*, the predominant lactic acid bacteria, *Lactobacillus brevis*, *Lactobacillus delbrueckii* subsp. *delbrueckii* and *Lactobacillus fermentum* were found in shalgam samples (Erginkaya and Hammes 1992; Arici 2004; Tangüler and Erten 2012a, b).

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