Current knowledge on antimicrobial metabolites produced from aromatic amino acid metabolism in fermented products

S. Naz, M. Cretenet and J.P. Vernoux

Research Unit Aliments Bioprocédés Toxicologie Environnements (URABTE) E.A. 4651, IFR146 ICORE, Université de Caen Basse-Normandie, Esplanade de la paix, 14032 CAEN cedex, France

Aromatic amino acids act as precursors of various low molecular weight (<1kDa) antimicrobial compounds including hydroxy acids such as phenyllactic acid, hydroxyphenyllactic acid, indolelactic acid, alcohols such as phenylethyl alcohol for example and others. These metabolites are known to play an important role in biopreservation of fermented food products as cheese, beer, sourdough, fermented vegetables and feed silage by inhibiting the growth of pathogens such as *Listeria monocytogenes*, *Staphylococcus aureus* and *Enterococcuss faecalis*. In addition to their antimicrobial properties, these aromatic metabolites can also influence the organoleptic characteristics, flavor and aroma profiles of fermented food products.

Keywords Fermented products, Antimicrobial metabolites, Biopreservation, Aromatic amino acid metabolism, secondary metabolites

1. Introduction

Human beings have always taken keen interest in developing methods, such as fermentation, to preserve and store their food over longer periods of time. With the advent in technology, the preservation methods have evolved to include techniques like freezing, pressure heating, drying and chemical preservation. A health conscious consumer society has made the food industry take great care in developing newer, healthier and safer alternatives to the classical preservation methods and chemicals. Although microbes are the prime reason behind the food and feed spoilage, the solution to deal with feed/food contamination problems also comes from the microbial world. The inherent ability of microorganisms to produce antagonistic compounds as a part of their natural defence mechanism can provide the food industry with natural and healthier alternatives to chemical preservatives. The current review illustrates the recent knowledge on the production pathways, antimicrobial potential and industrial applications of certain secondary metabolites produced in some fermented products by aromatic amino acid degradation.

2. Fermented products and biopreservation

Fermentation has been a traditional method for food preservation in various cultures and civilizations. A number of raw foods including vegetables, grains, legumes, milk and meat are preserved through fermentation [1]. The resulting products range from beer, cheese, kefir, yogurt and bread, vegetables such as sauerkraut and kimchi as well as animal feed silage. The process of fermentation enhances nutrient accessibility in some foods, such as bread, detoxifies some other materials, such as cassava, and is responsible for the development and/or improvement of flavor and texture of the fermented product [2].

A fermentation ecosystem is consisted of microorganisms (yeasts and bacteria), organic substrate to be fermented, fermentation medium, and various tools and parameters for monitoring and developing the fermentation process [3]. The fermentation process is basically dependent on the transformation of carbohydrates, proteins and lipids to acidic, alcoholic and organic metabolites. As a consequence, the pH of the ecosystem is reduced and it enhances the colonization of the starter and non-starter microbiota. At the same time, there is some inhibition of the growth of pathogenic and spoilage microbes [2,3]. For example, fermentation of bread dough to sourdough stabilizes and increases levels of various antagonistic compounds which consequently extends the shelf life of bread [4]. However, the acidic pH of the fermentation ecosystem is not the only factor behind the preservative potential of fermented products. Other factors such as the production of low molecular weight bioactive peptides e.g. bacteriocins, production of carbon dioxide and sulphur dioxide, low redox potential, hydrogen peroxide, alcohols like ethanol, and depletion of nutrients as a result of microbial crowding, also play a role in maintaining environmental conditions that will preclude the growth of food borne pathogens and spoilage organisms in fermented products[5–9].

The microorganisms in fermented products can either be present as wild indigenous flora carrying out spontaneous food fermentation, or can be added via back-slopping or as additional starter cultures [10]. Safety enhancement of fermented products with selected bacterial and yeast strains that are able to inhibit the growth of undesirable microorganisms requires an insight in their interactions within these fermentation systems for maintaining the sensory quality as well as for careful starter culture design [11]. For example, in a recent study, application of Kefir grain back slope cultures to sourdough bread and cheeses resulted in a food product more resistant to spoilage and against development of pathogenic bacteria such as coliforms, *Enterobacteria* and *Staphylococci*. The freeze-dried kefir grains also accelerated the ripening process [12]. Therefore, the proper selection and use of the microorganism applied as well as the knowledge of antimicrobial compounds and proteinaceous substances produced by these starter cultures, the production pathways, genes and enzymes involved in the production of these allelopathic compounds is of great importance in fermentation industry. Table 1 enlists some of the common fermentation products and principal starter cultures present in these products.

Table 1 Presentation of some fermented products and corresponding principal microorganisms

Fermented Product	Fermentation type	Reaction products	Principal starter/non-starter microorganisms	Ref.
Kimchi	Heterofermentative lactococci, and homofermentative lactobacilli	Lactate, carbon dioxide, ethanol, and acetate, mannitol	*Leuconostoc mesenteroides*, *Lactobacillus sake*, *Lactobacillus brevis*, *Streptococcus* spp., *Pediococcus* spp., *Weissella* spp., *Leuconostoc citreum* and *Lactobacillus plantarum*	[13,14]
Beer	Alcoholic fermentation	Carbon dioxide, ethanol, dextrin	*Saccharomyces cerevisiae, S. bayanus, S. pastorianus, S. paradoxus, Candida tropicalis*	[15,16]
Wine	Alcoholic, malolactic	Ethanol, malic acid	*Oenococcus oeni , Lactobacillus plantarum*	[17]
Sourdough	Alcoholic, Heterofermentation	Ethanol and ethyl acetate, 2-methyl-propanol and 2/3-methyl-1-butanol, d/l-lactic and acetic acids	*Bifidobacterium pseudocatenulatum, Lactobacillus sanfrancisco, Saccharomyces cerevisiae, Lactobacillus pontis, Lactobacillus brevis, Lactobacillus plantarum, Lactobacillus paralimentarius, Lactobacillus rossiae, Lactobacillus sanfranciscensis, Lactobacillus amylovorus, , Lactobacillus fermentum, Lactobacillus reuteri*	[18–20]
Cheese	Homolactic + Heterolactic	Lactic acid, propionic acid, acetic acid,	*Lactococcus lactis, Streptococcus thermophilus*, *Debaryomyces hansenii*, *Geotrichum candidum Penicillium camemberti*, *Arthrobacter arilaitensis*, *Brevibacterium aurantiacum*, *Brevibacterium linen, Corynebacterium casei* *Halomonas* spp., *Hafnia alvei*, *Leuconostoc* sp., *Psychrobacter sp.,Kluyveromyces marxianus*	[21–23]
Kefir	Heterolactic	Alcohol, lactic acid	*Lactobacillus kefiranofaciens ssp. kefirgranum, Lactobacillus parakefiri, Lactobacillus kefiri, Kluyveromyces marxianus, Kazachstania exigua, Rhodosporidium kratochvilovae*, *Streptococcaceae* (primarily *Lactococcus* spp.), *Gluconobacter japonicus* and *Lactobacillus uvarum, Lactobacillus helveticus, Acetobacter syzygii, Lactobacillus satsumensis*	[24]
Sauerkraut	Heterolactic + Homolactic	Acetic acid , Lactic acid	*Leuconostoc mesenteroides, Lactobacillus plantarum, Pediococcus acidilactici*	[10,25]
Fermented feed		Lactic acid	*Enterococcus faecium*, *Lactobacillus plantarum*, *Lactococcus lactis*, *Pediococcus pentosaceu*s (syn. *Pediococcus acidilactici*)	[26]

3. Amino acids and aromatic aminoacids in fermented products

The starter and non-starter ripening flora hydrolyzes carbohydrates and sugars as part of their primary metabolic activities in fermented products. As a consequence, proteolysis, mainly done by the yeasts strains, is also enhanced. For example, in dairy products such as cheese, metabolism of lactose to lactic acid by bacteria reduces the pH and boosts the primary proteolysis of milk proteins [27]. The initial degradation of α_{s1}-casein is carried out by microbial enzymes and/or rennet enzymes or by acids – whereas α_{s2}-casein, κ-casein and β-casein are degraded by the activity of plasmin [28]. The residual coagulant enzymes (chymosin or pepsin), milk enzymes (plasmin) and microbial enzymes hydrolyze the proteins to small peptides and amino acids by the action of bacterial and fungal peptidases [29–32]. In the case of sourdough bread, proteolysis is carried out by flour enzymes and microbial enzymes of sourdough bacteria. The proteolytic system of *Lactobacillus sanfranciscensis,* an important starter strain*,* includes proteinases, dipeptidases and aminopeptidases [33]. Depending upon the homo- and heterofermentative potential of the microbial flora, a varied spectrum of different amino acids is produced in different products. These free amino acids in turn affect the bread crust flavor according to the proteolytic potential of the microbial species employed e.g. *Saccharomyces cerevisiae* has a greater effect on crust flavour than *Candida krusei* [34].

Amino acids are an important group of organic molecules characterized by the presence of amine and carboxylic acid functional groups, along with side-chain specific to each amino acid [35]. The side chain found in the three proteinogenic aromatic amino acids (AAA) namely phenylalanine (phe), tryptophan (trp), and tyrosine (tyr) consists of a common aromatic ring structure [36]. The characteristic UV light absorbtion maxima for these aromatic amino acids falls between the range of 260 (phe) to 280 nm (trp, tyr) which provides the basis for the separation of these compounds through chromatography and protein quantification [36]. Aromatic amino acids are essential components of protein synthesis in animals and plants, and can serve also as precursors for a wide range of secondary metabolites with various nutritional, safety and health effects [37]. These aromatic amino acids are naturally present in many foods such as wine, cheese, wheat and other plant raw materials and are of particular importance for food, feed and pharmaceutical industry due to their applications as aroma, flavor, and/or as precursors of antimicrobial compounds [38–44]. Table 2 provides the reported concentrations of free aromatic amino acids in some fermented food/feed or their substrates.

Table 2 Concentrations of free aromatic amino acids in various fermentation products.

Fermented product	Amino acid Concentration (mg/100g or100ml)			Reference
	Phenylalanine	Tryptophan	Tyrosine	
Cheese	142.1	14	17.1	[45]
Beer (Wort)	16.12	13.07		[46]
Kefir		3.37	0.44	[47]
Kimchi	0.07-1.03	0.08-1.19	0.12-0.22	[48,49]
Wine	0.28-13.8	9.55	1.73	[17,50]
Fermented feed	460-5830	70-1300	430-5060	[51]

Among the free amino acids, phenylalanine is reported as one of the dominant free amino acid in soft cheese varieties as ewe milk's cheese as well as in hard cheese varieties such as cheddar [52,53]. In longan wine fermented with mixed yeasts population, phenylalanine is one of the amino acids specifically added to enhance the production of targeted aroma compounds [54]. In beer, the presence of phenylalanine and tyrosine is desirable for the fullness, nutritional value, quality and safety of the product [55]. Similarly, in sourdough, phenylalanine along with ornithine, methionine, leucine, isoleucine, and valine is one of the most important amino acids contributing towards the flavor and aroma of wheat bread [56].

4. Major antimicrobial metabolites from AAA metabolism

Aromatic amino acids are known to produce secondary metabolites with antimicrobial activities such as phenyllactic acid from phenylalanine, indole lactic acid from tryptophan, and hydroxyphenyl lactic acid from tyrosine [40]. Hydroxy phenyllactic acid produced from tyrosine has a weaker activity and a similar antimicrobial spectrum as phenyllactic acid, and therefore was not frequently studied in literature [40]. However tyrosine metabolites are supposed to be structurally related to those of phe since tyr is hydroxylated phe. Figure 1 depicts the metabolic pathways with precursor amino acids and their secondary metabolites. A detailed account on the production pathways, genes and enzymes for these metabolites is given in the following sections.

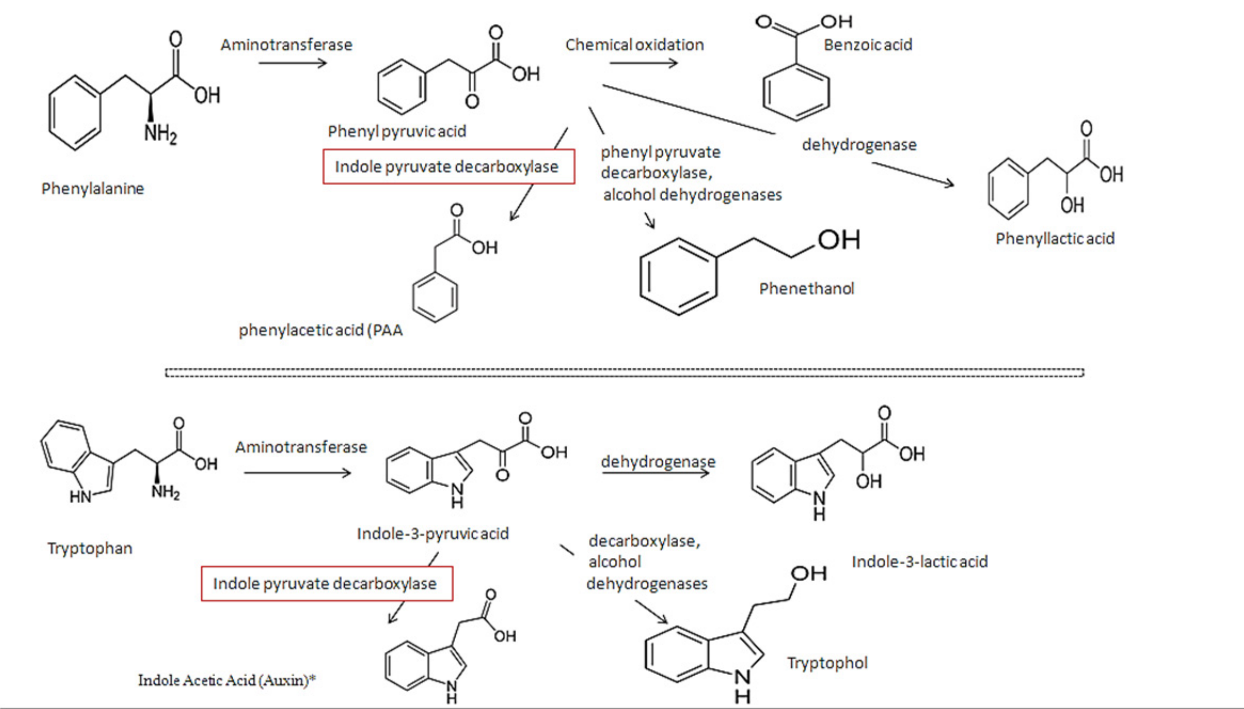

Fig. 1 Major antimicrobial compounds produced through the metabolism of the two main aromatic amino acids. * Auxin is not known as antimicrobial compound.

4.1. Phenyllactic acid

3-Phenyllactic acid (2-hydroxy-3-phenylpropanoic acid or ß-phenyllactic acid, PLA), an organic acid, is a broad-spectrum antimicrobial compound with activity against bacteria, moulds and fungi including yeasts [57–60]. The molecular formula and molecular weight of PLA are $C_9H_{10}O_3$ and 166 g.mol^{-1}, respectively. Certain *L. plantarum* strains such as *L. plantarum* 1081, *L. plantarum* 778, *L. plantarum* 1073 and *L. plantarum* CECT-221 can produce PLA in quantities as high as 5.2, 4.1, 2.6, 1 and 1.38 mM PLA *in vitro*, respectively while yeast strains like *Geotrichum candidum* can produce 5.2 mM of PLA [28,40,61]. The target site for the antimicrobial action of PLA is the microbial cell wall. Scanning electron microscope studies showed that the cell wall structure of the bacteria exposed to PLA was damaged, even broken. The bacteria formed aggregates and secreted polysaccharides; then, the cell wall lost rigidity, causing the cells to swell, even collapse [61]. PLA has relatively high minimum inhibitory concentration (MIC) value for anti-yeast activity (50 to more than 500 mM at pH 4.0 to 6.0) and against moulds at pH 4.0 is 45 mM and decreases with decreasing pH [61,62]. PLA exists in two chiral isomers: D- and L-PLA, whereby D-PLA exhibiting a stronger antimicrobial activity than L-PLA [57].

In lactic acid bacteria (LAB) and yeasts, PLA has been reported to be a reaction product of amino acid metabolism [63]. Phenylalanine is transaminated to phenylpyruvic acid (PPA) and PPA is further reduced to PLA [30,64-65]. The transamination reaction is initiated by an aromatic aminotransferase (AAT) with a broad substrate spectrum, including leucine, tyrosine, tryptophan, and methionine [66]. AAT catalyzes the transfer of the amino group from the amino acid to a suitable alpha-keto acid acceptor in most LAB strains [64, 66]. Therefore, alpha- ketoglutarate has important effect on phenylalanine catabolism and impacts the regulation of PLA biosynthesis indirectly [65, 67]. For example, in the presence of substrates like glucose, citrate, or fructose the formation of alpha-ketoglutarate is reinforced by the enhanced activity of glutamate dehydrogenase, which can in turn upregulate the production of PLA [65, 67]. In *Yarrowia lipolytica*, the expression of genes for General amino acid permease (*GAP1*), and Branched amino acid transferases (*BAT2/ BAT1*) are induced upon amino acid addition [68]. In LAB, different types of dehydrogenases have been reported to convert PPA to PLA, and lactate dehydrogenase (LDH) is the main type [69]. In addition to LDH, some other dehydrogenases including D-form dehydrogenases such as D-hydroxyisocaproate dehydrogenase (D-HicDH) from *Lactobacillus casei* [70] and the D-mandelate dehydrogenase (D-ManDH) from *Enterococcus faecalis* [71] and *Lactobacillus curvatus* [72] are involved in the catalytic dehydrogenation activity. These D form dehydrogenases show broad substrate specificity to 2-ketoacids including phenylpyruvate [69]. Especially, *L. casei* D-HicDH and *L. curvatus* D-ManDH show relatively high specificity to phenylpyruvate [70, 72]. Phenyllactic acid (PLA) is a metabolite naturally present in various honeys such as unifloral honeys where its concentration reaches as high as 100 to 800 mg/kg [73]. In heather, ling heather, and manuka honeys, the concentration of PLA reach up to 820, 875, and 243 mg/kg, respectively [74,75].

This organic acid has been shown to exert some positive immunomodulatory effects in poultry whereby improving the production performance and egg quality [76]. Additionally, when used as a feed additive in the diet of chicks, PLA exhibits antipathogenic activity in the large intestine, and enhances the meat quality [77]. Similar immunomodulatory and antipathogenic effects were observed when PLA was added to the feed of weanling and growing pigs [78].

It is worth to mention that PLA is an analogue of "Danshensu" from Chinese medicine which is presently applied as a pharmaceutical agent for the treatment of coronary disease [79]. In cosmetic industries, PLA is marketed as an anti-aging agent that helps in reducing skin wrinkles [80].

4.2. Indole lactic acid

Another hydroxy acid produced as a result of aromatic amino acid metabolism is indole lactic acid (ILA). The molecular formula and molecular weight of indole lactic acid are $C_{11}H_{11}NO_3$ and 205.2 g.mol-1 respectively. 3-indolelactic acid (3-ILA) is produced as a result of tryptophan metabolism in some yeast and bacterial species such as *Candida* spp. and *Bifidobacterium* [81,82].

ILA inhibits the growth of Gram positive and Gram negative bacteria at a concentration of 6 mM for *Escherichia coli* and 15 mM for *Bacillus cereus* [81]. Microbial pathways for tryptophan degradation in cheese to produce ILA may involve several enzymes including a tryptophan aminotransferase (EC 2.6.1.27)[83], Tryptophan (trp) decarboxylase (EC 4.1.1.28), and indole-3-lactic acid dehydrogenase (EC 1.1.1.110) [70]. Gao et al. [84] showed that the catabolism of trp by aminotransferase to indole-3-pyruvic acid (IPyA) was possible under conditions found in ripening cheese (pH 5.2, 4% NaCl, 13°C. Despite its great antimicrobial potential, the use of ILA in cheese is disadvantageous as the indole compounds are considered unclean off-flavors in food products [85,86].

4.3. Aromatic alcohols

Another metabolite of interest from aromatic amino acid metabolism is Phenylethyl alcohol (PEA). PEA is a higher aromatic alcohol with a rose-like odour, alternatively known as 2-Phenylethanol (2-PE). The molecular formula and molecular weight of phenylethyl alcohol is $C_6H_5CH_2CH_2OH$ and 122.16 g.mol-1 respectively.

PEA is a bacteriostatic agent and can cause reversible inhibition of the synthesis of bacterial deoxyribonucleic acid at low concentrations e.g. 0.25-0.4% [87–89]. At higher dosage (90 to 180 mM), the target site of inhibitory action seems to be the plasma membrane, where transport systems for sugars and amino acids are affected. Furthermore, the permeability of the membrane increases, thus accelerating the passive diffusion of ions and small metabolites through the membrane [90]. It has been employed for selective isolation of Gram-positive bacteria as it inhibits the growth of Gram-negative bacteria, including *Salmonella, Shigella, Aerobacter, Klebsiella, Escherichia, Pseudomonas* and *Proteus* [91]. However, the concentration of PEA is also important to cause an antimicrobial effect. *Kluyveromyces marxianus* caused an antimicrobial effect by the production of exogenous PEA at a concentration of 2.0 g^{l-1} [92] while it took 4 g^{l-1} in *Saccharomyces cerevisiae* to cause the same effect [93].

The most prominent microorganisms regarding production of natural 2-PE are yeasts. Yeasts can produce phenylethyl alcohol by decarboxylation and deamination of phenylalanine during alcoholic fermentation or via phenylpyruvate by means of de novo synthesis during phenylalanine biosynthesis process. However, the commonly accepted route from Phe to PEA is by transamination of the amino acid to phenylpyruvate, decarboxylation to phenylacetaldehyde and reduction to PEA [93]. In *Saccharomyces cerevisae*, *AAD* genes (putative aryl alcohol dehydrogenases), are involved in the final step of amino acid catabolism in which a long chain or complex alcohol is produced as a result of the activity of any one of the ethanol dehydrogenases *(Adh1p, Adh2p, Adh3p, Adh4p, Adh5p)*. Alternatively, 3-phenylpyruvate is decarboxylated to 2-phenylacetaldehyde, which is subsequently reduced to 2-phenylethanol. In *Saccharomyces cerevisiae*, decarboxylation of 3-phenylpyruvate can proceed if any one of the four genes, *PDC1*, *PDC5*, *PDC6*, or *YDR380w*, is functional [44].

Phenylethyl alcohol (PEA) possesses a characteristic rose-like aroma and is a desirable flavour molecule in various alcoholic beverages. The characteristic rose fragrance is desirable in the perfume and cosmetics industry [92,94]. Other fermented food products where PEA is naturally present include tea leaves, cocoa, coffee [95], bread [96], cider [97] and soy sauce [98]. PEA has also been shown to prolong the shelf life and quality of strawberries [99]. In red wines, during syrah must alcoholic fermentation, PEA is one of the major alcohols produced at a concentration of 13.3 mg l^{-1} to70.6 and in beer, at the concentrations of 11 to 51mg l^{-1} [15,100]. In certain cheese varieties, production of PEA has been observed immediately as a result of phenylalanine metabolism[101,102] .

A second important aromatic alcohol with antipathogenic activities is tryptophol. In wines, tryptophol significantly affects the viability of *Campylobacter jejuni*, but at concentrations which are not normally present in wines (above 100 mg/L)[103,104]. In another study, tyrosol (from tyrosine) and tryptophol showed weak inhibitory effect in wines against respiratory pathogens such as *Moraxella catarrhalis* and *Psuedomonas aeruginosa* [105].

4.4. Phenolic compounds (Benzoic Acid)

Another metabolite of phenylalanine metabolism in cheese is benzoic acid. In food industry, benzoic acid has been widely employed as a natural preservative under code number E210. The antimicrobial activity of *Lactobacillus plantarum* originally isolated from beer, yoghurt and orange juice against fungi, yeasts and some Gram-negative bacteria has been associated to the production of benzoic acid [106,107]. In other reports, the antimicrobial activity of this organic acid has been demonstrated against a variety of food spoilage and pathogenic microorganisms such as *Escherichia coli, Listeria monocytogenes, Aspergillus* sp. and *Penicillium* sp.[108]. Starter LAB strains in 6 varieties of kefir, including *Lactobacillus kefiri, Lactobacillus delbrueckii* ssp *bulgaricus, Lactococcus lactis, Streptococcus thermophilus* and *Leuconostoc mesenteroides* and one yeast *Kluyvermyces marxianus* have also been shown to produce benzaldehyde and benzoic acid[109]. Small concentrations of benzoic acid as a unique aroma compound by strains of *Lactobacillus plantarum*, *Lactobacillus sanfranciscensis*, *Lactobacillus brevis* and *Lactobacillus delbrueckii* subsp *bulgaricus* was observed in Chinese mantou, also known as fermented sourdough steamed bread [110].
Benzoic acid is produced from phenylalanine in cell extracts through the phenylpyruvic acid pathway. Phenylpyruvic acid was initially converted to phenylpyruvic acid by an aminotransferase and the keto acid was further transformed to benzaldehyde and benzoic acid through a chemical oxidation step [111].

4.5. Miscellaneous

In raw plant, aromatic amino acids are also the precursors for antimicrobial secondary metabolites such as glucosinolates that are produced naturally during amino acid metabolism. Some examples of glucosinolates synthesized either from tryptophan include glucobrassicin, 4-OH (hydroxy) glucobrassicin, 4-MeO (methoxy) glucobrassicin and examples from phenylalanine and tyrosine include glucotropaeolin, gluconasturtin, and sinalbin. The hydrolysis products of these molecules such as allylisothiocyanate, benzylisothiocyanate and 2-phenylethylisothiocyanate have been shown to exhibit antimicrobial activities against *Escherichia coli*, *Pseudomonas aeruginosa, Listeria monocytogenes* and *Staphylococcus aureus* [112]. Glucosinolates are decomposed by the enzyme myrosinase (a thioglucosidase; EC 3.2.3.1). In fermented vegetables such as sauerkraut, *Lactobacillus sakei* was found to be the most efficient starter culture strain that hydrolyzed glucosinolates 2–3 times more compared to *Lactobacillus plantarum*, *Leuconostoc mesenteroides*, *Lactococcus lactis* and *Pediococcus pentosaceus* strains, resulting in the production of sinigrin, glucoiberin, and glucobrassicin. Cabbage juices fermented with these starter strains inhibited the growth of *Candida lambica*, and *Escherichia coli* [113]. A hydrolysis product of sinigrin, Allyl isothiocyanate, has been shown to exhibit very strong inhibitory activity towards bacteria as well as oxidative and fermentative yeasts. The minimum inhibitory concentration was estimated to be between 50 and 500 ppm for bacteria, including Gram postive, Gram negative, pathogenic, and lactic acid bacteria [114]. Another antimicrobial compound, phenylacetic acid (PAA), an auxin-like molecule, has been isolated from the culture extracts of *Azospirillum brasilense*. In the presence of phenylalanine as substrate in minimal growth medium, the biosynthesis of PAA was found to be mediated by the indole-3-pyruvate decarboxylase, which has been identified as the key enzyme in indole-3-acetic acid (IAA) (Auxin) production [115].

5. Conclusion

The production of organic, low molecular weight acidic and alcoholic metabolites as a result of aromatic amino acids in fermented foods can enhance the antimicrobial potential of the microbial flora. In fermented products especially cheese, their applicability can be beneficial as they possess appreciable lipid solubility which allows them to diffuse more freely through the matrix. In other acidic food/feed products as well, the liposolubility of these acids allows them to diffuse across the bacterial plasma membrane into the cytoplasm which makes these metabolites very effective against pathogenic bacteria [116]. However, certain food borne pathogens like *L. monocytogenes* have shown enhanced acid adaptation and survival potential in dairy products, including cottage cheese, yogurt, and whole-fat cheddar cheese. Therefore, the use of bioprotective cultures as an adjunct in fermented food products is necessary.

References

[1] Kanekanian A. Fermented foods and beverages of the world (2010). *International Journal of Dairy Technology* 2012;65:158–158.

[2] Ivey M, Massel M, Phister TG. Microbial interactions in food fermentations. *Annual Reviews in Food Sciences & Technology* 2013;4:141–62.

[3] Scott R. Fermentation ecosystems. *Handbook of Animal-Based Fermented Food Beverage Technology*. Second Ed., CRC Press; 2012, p. 153–63.

[4] Katina K, Arendt E, Liukkonen K-H, Autio K, Flander L, Poutanen K. Potential of sourdough for healthier cereal products. *Trends in Food Sciences & Technology* 2005;16:104–120.

[5] Dertli E, Sert D, Akin N. The effects of carbon dioxide addition to cheese milk on the microbiological properties of Turkish white brined cheese. *International Journal of Dairy Technology* 2012;65:387–92.
[6] Imran M, Bré J-M, Guéguen M, Vernoux J-P, Desmasures N. Reduced growth of *Listeria monocytogenes* in two model cheese microcosms is not associated with individual microbial strains. *Food Microbiology* 2013;33:30–9.
[7] Díez L, Rojo-Bezares B, Zarazaga M, Rodríguez JM, Torres C, Ruiz-Larrea F. Antimicrobial activity of pediocin PA-1 against *Oenococcus oeni* and other wine bacteria. *Food Microbiology* 2012;31:167–72.
[8] Liu S-Q, Tsao M. Biocontrol of dairy moulds by antagonistic dairy yeast *Debaryomyces hansenii* in yoghurt and cheese at elevated temperatures. *Food Control* 2009;20:852–5.
[9] Pawlowska AM, Zannini E, Coffey A, Arendt EK. Green Preservatives: Combating fungi in the food and feed industry by applying antifungal Lactic Acid Bacteria. *Advanced Food Nutritional Research*. Academic Press; 2012, p. 218–32.
[10] Leroy F, De Vuyst L. Lactic acid bacteria as functional starter cultures for the food fermentation industry. *Trends in Food Science & Technology* 2004;15:67–78.
[11] Lan W, Chen Y, Wu H, Yanagida F. Bio-protective potential of lactic acid bacteria isolated from fermented wax gourd. *Folia Microbiology* (Praha) 2012;57:99–105.
[12] Plessas S, Alexopoulos A, Voidarou C, Stavropoulou E, Bezirtzoglou E. Microbial ecology and quality assurance in food fermentation systems. The case of kefir grains application. *Anaerobe* 2011;17:483–5.
[13] Kim J, Bang J, Beuchat LR, Kim H, Ryu JH. Controlled fermentation of Kimchi using naturally occurring antimicrobial agents. *Food Microbiology* 2012;32:20–31.
[14] Jung JY, Lee SH, Lee HJ, Seo HY, Park WS, Jeon CO. Effects of *Leuconostoc mesenteroides* starter cultures on microbial communities and metabolites during Kimchi fermentation. *International Journal of Food Microbiology* 2012;153:378–87.
[15] Verbelen P, Delvaux F. Brewing yeast in action: Beer fermentation. *Applied Mycology*. CABI; 2009, p. 110–22.
[16] N'Guessan FK, N'Dri DY, Camara F, Djè MK. *Saccharomyces cerevisiae* and *Candida tropicalis* as starter cultures for the alcoholic fermentation of tchapalo, a traditional sorghum beer. *World Journal of Microbiology & Biotechnology* 2010;26:693–9.
[17] Pozo-Bayon MA, G-Alegria E, Polo MC, Tenorio C, Martin-Alvarez PJ, Calvo de la Banda MT, et al. Wine volatile and amino acid composition after malolactic fermentation: Effect of *Oenococcus oeni* and *Lactobacillus plantarum* starter cultures. *Journal of Agricultural Food Chemistry* 2005;53:8729–35.
[18] Sanz-Penella JM, Tamayo-Ramos JA, Haros M. Application of *Bifidobacteria* as starter culture in whole wheat sourdough breadmaking. *Food Bioprocess Technology* 2012;5:2370–80.
[19] Hansen B, Hansen Å. Volatile compounds in wheat sourdoughs produced by lactic acid bacteria and sourdough yeasts. *Zeitschrift fuer Lebensmittel-Untersuchung und -Forschung* 1994;198:202–9.
[20] De Vuyst L, Vrancken G, Ravyts F, Rimaux T, Weckx S. Biodiversity, ecological determinants, and metabolic exploitation of sourdough microbiota. *Food Microbiology* 2009;26:666–75.
[21] Larpin-Laborde S, Imran M, Bonaïti C, Bora N, Gelsomino R, Goerges S, et al. Surface microbial consortia from Livarot, a French smear-ripened cheese. *Canadian Journal of Microbiology* 2011;57:651–60.
[22] Callon C, Delbès C, Duthoit F, Montel M-C. Application of SSCP-PCR fingerprinting to profile the yeast community in raw milk Salers cheeses. *Systematic & Applied Microbiology* 2006;29:172–80.
[23] Delbès C, Ali-Mandjee L, Montel M-C. Monitoring bacterial communities in raw milk and cheese by culture-dependent and -independent 16S rRNA gene-based analyses. *Applied Environmental Microbiology* 2007;73:1882–91.
[24] Vardjan T, Mohar Lorbeg P, Rogelj I, Čanžek Majhenič A. Characterization and stability of lactobacilli and yeast microbiota in kefir grains. *Journal of Dairy Sciences* 2013;96:2729–36.
[25] Ravyst F, De Vuyst L. Leroy F, Bacterial diversity and functionalities in food fermentation. *Engineering in Life Sciences.* 2012; 12: 356-367.
[26] Olstorpe M, Axelsson L, Schnürer J, Passoth V. Effect of starter culture inoculation on feed hygiene and microbial population development in fermented pig feed composed of a cereal grain mix with wet wheat distillers grain. *Journal of Applied Microbiology* 2010;108:129–38.
[27] Van Kranenburg R, Kleerebezem M, van Hylckama Vlieg J, Ursing BM, Boekhorst J, Smit BA, et al. Flavour formation from amino acids by lactic acid bacteria: predictions from genome sequence analysis. *International Dairy Journal* 2002;12:111–21.
[28] Rodrigues D, Rocha-Santos TAP, Freitas AC, Duarte AC, Rocha-Santos TAP, Freitas AC, et al. Analytical strategies for characterization and validation of functional dairy foods. *Trends in Analytical Chemistry* 2012;41:27–45.
[29] Rattray FP, Fox PF. Aspects of enzymology and biochemical properties of *Brevibacterium linens* relevant to cheese ripening: a review. *Journal of Dairy Sciences* 1999;82:891–909.
[30] McSweeney PLH, Sousa MJ. Biochemical pathways for the production of flavor compounds in cheeses during ripening: A review. *Le Lait* 2000;80:293–324.
[31] González-Martín I, Hernández-Hierro JM, Vivar-Quintana A, Revilla I, González-Pérez C. The application of near infrared spectroscopy technology and a remote reflectance fibre-optic probe for the determination of peptides in cheeses (cow's, ewe's and goat's) with different ripening times. *Food Chemistry* 2009;114:1564–9.
[32] Skeie S, Feten G, Almøy T, Østlie H, Isaksson T. The use of near infrared spectroscopy to predict selected free amino acids during cheese ripening. *International Dairy Journal* 2006;16:236–42.
[33] Gobbetti M, Smacchi E, Corsetti A. The proteolytic system of *Lactobacillus sanfrancisco* CB1: purification and characterization of a proteinase, a dipeptidase, and an aminopeptidase. *Applied Environmental Microbiology* 1996;62:3220–6
[34] Spicher G, Nierle W. Proteolytic activity of sourdough bacteria. *Applied Microbiology & Biotechnology* 1988;28:487–92.
[35] Petkova V, Obreshkova D, Vodenicharov E, Hadjieva B, Koleva N, Petkova E, et al. Essential amino acids-Review of some of the contemporary analytical methods for detection. *World Journal of Pharmacy & Pharmaceutical Sciences* 2013; 2:2 658-666
[36] Sprenger G. Aromatic Amino Acids. In: *Amino acid biosynthetic pathways regulation of metabolic engineering* Wendisch V, editor. vol. 5, Springer Berlin Heidelberg; 2007, p. 93–127.

[37] Tzin V, Galili G. New insights into the shikimate and aromatic amino acids biosynthesis pathways in plants. *Molecular Plant* 2010;3:956–72.

[38] McCarthy AL, O'Callaghan YC, O'Brien NM. Protein hydrolysates from agricultural crops—Bioactivity and potential for functional food development. *Agriculture* 2013;3:112–30.

[39] Rodríguez-Pazo, Noelia, Laura Vázquez-Araújo, Noelia Pérez-Rodríguez, Sandra Cortés-Diéguez, José Manuel Domínguez. Cell-free supernatants obtained from fermentation of cheese whey hydrolyzates and phenylpyruvic acid by *Lactobacillus plantarum* as a source of antimicrobial compounds, bacteriocins, and natural aromas." *Applied Biochemistry & Biotechnology* (2013): 1-19.

[40] Naz S, Gueguen-Minerbe M, Cretenet M, Vernoux J-P. Aromatic amino acids as precursors of antimicrobial metabolites in *Geotrichum candidum. FEMS Microbiology Letters* 2013.

[41] Arrieta MP, Prats-Moya MS. Free amino acids and biogenic amines in Alicante Monastrell wines. *Food Chemistry* 2012;135:1511–9.

[42] Burns P, Cuffia F, Milesi M, Vinderola G, Meinardi C, Sabbag N, et al. Technological and probiotic role of adjunct cultures of non-starter lactobacilli in soft cheeses. *Food Microbiology* 2012;30:45–50.

[43] Mcfeeters R. Fermentation microorganisms and flavor changes in fermented foods. *Journal of Food Sciences* 2004;69:35–7.

[44] Dickinson JR, Salgado LEJ, Hewlins MJE. The catabolism of amino acids to long chain and complex alcohols in *Saccharomyces cerevisiae. Journal of Biological Chemistry* 2003;278:8028–34.

[45] Tamime AY, Dalgleish DG, Banks W. *Feta and Related Cheeses*. Robinson RK, Tamime AY, editors. Woodhead Publishing; 1991 p.11-44.

[46] Fumi MD, Galli R, Lambri M, Donadini G, Faveri DM. Impact of full-scale brewing processes on lager beer nitrogen compounds. *European Food Research & Technology* 2009;230:209–16.

[47] Irigoyen A, Ortigosa M, García S, Ibáñez FC, Torre P. Comparison of free amino acids and volatile components in three fermented milks. *International Journal of Dairy Technology* 2012;65:578–84.

[48] Cheigh H, Park K, Lee CY. Biochemical, microbiological, and nutritional aspects of Kimchi (Korean fermented vegetable products). *Critical Reviews in Food Sciences & Nutrition* 1994;34:175–203.

[49] Song HP, Kim D-H, Yook H-S, Kim M-R, Kim K-S, Byun M-W. Nutritional, physiological, physicochemical and sensory stability of gamma irradiated Kimchi (Korean fermented vegetables). *Radiation Physics & Chemistry* 2004;69:85–90.

[50] Bell SJ, Henschke PA. Implications of nitrogen nutrition for grapes, fermentation and wine. *Australian Journal of Grape & Wine Research* 2005;11:242–95.

[51] Li X, Rezaei R, Li P, Wu G. Composition of amino acids in feed ingredients for animal diets. *Amino Acids* 2010;40:1159–68.

[52] Mikulec N, Habuš I, Antunac N, Vitale L, Havranek J. Free amino acid profile during ripening of ewe's milk cheese from the Croatian island Krk. *International Journal of Dairy Technology* 2013

[53] Subramanian A, Alvarez VB, Harper WJ, Rodriguez-Saona LE. Monitoring amino acids, organic acids, and ripening changes in Cheddar cheese using Fourier-transform infrared spectroscopy. *International Dairy Journal* 2011;21:434–40.

[54] Trinh TTT, Woon WV, Yu B, Curran P, Liu SQ. Effect of L-isoleucine and L-phenylalanine addition on aroma compound formation during longan juice fermentation by a co-culture of *Saccharomyces cerevisiae* and *Williopsis saturnus*. *South African Journal of Enology & Viticulture* 2010;31:116.

[55] Zhu L, Hu Z, Gamez G, Law W, Chen H, Yang S, et al. Simultaneous sampling of volatile and non-volatile analytes in beer for fast fingerprinting by extractive electrospray ionization mass spectrometry. *Annals of Bioanalytical Chemistry* 2010;398:405–13.

[56] Thiele C, Gänzle MG, Vogel RF. Contribution of sourdough lactobacilli, yeast, and cereal enzymes to the generation of amino acids in dough relevant for bread flavor. *Cereal Chemistry* 2002;79:45–51.

[57] Dieuleveux V, Van Der Pyl D, Chataud J, Gueguen M. Purification and characterization of Anti-Listeria compounds produced by *Geotrichum candidum. Applied Environmental Microbiology* 1998;64:800–3.

[58] Lavermicocca P, Valerio F, Visconti A. Antifungal activity of phenyllactic acid against molds isolated from bakery products. *Applied Environmental Microbiology* 2003;69:634–40.

[59] Ohhira I, Kuwaki S, Morita, H, Suzuki T, Tomita, S, Hisamatsu, S, et al. Identification of 3-phenyllactic acid as a possible antibacterial substance produced by *Enterococcus faecalis* TH10. *Biocontrol Sciences & Technology* 2004;9:77–81.

[60] Schwenninger SM, Lacroix C, Truttmann S, Jans C, Spörndli C, Bigler L, et al. Characterization of low-molecular-weight antiyeast metabolites produced by a food-protective *Lactobacillus-Proponibacterium* coculture. *Journal of Food Protection* 2008;71:2481–7.

[61] Gerez CL, Carbajo MS, Rollán G, Torres Leal G, Font de Valdez G. Inhibition of citrus fungal pathogens by using lactic acid bacteria. *Journal of Food Sciences* 2010;75:M354–359.

[62] Dieuleveux V, Lemarinier S, Guéguen M. Antimicrobial spectrum and target site of -3-phenyllactic acid. *International Journal of Food Microbiology* 1998;40:177–83.

[63] Valerio F, Lavermicocca P, Pascale M & Visconti A (2004) Production of phenyllactic acid by lactic acid bacteria: an approach to the selection of strains contributing to food quality and preservation. *FEMS Microbiology Letters* 233: 289–295.

[64] Yvon M & Rijnen L (2001) Cheese flavour formation by amino acid catabolism. *International Dairy Journal* 11: 185–201.

[65] Vermeulen N, Ganzle MG & Vogel RF (2006) Influence of peptide supply and cosubstrates on phenylalanine metabolism of *Lactobacillu sanfranciscensis* DSM20451(T) and *Lactobacillus plantarum* TMW1.468. *Journal of Agricultural Food Chemistry* 54: 3832–3839.

[66] Yvon M, Thirouin S, Rijnen L, Fromentier D & Gripon JC (1997) An aminotransferase from *Lactococcus lactis* initiates conversion of amino acids to cheese flavor compounds. *Applied Environmental Microbiology* 63: 414–419.

[67] Dallagnol AM, Catalán CAN, Mercado MI, Font de Valdez G & Rollán GC (2011) Effect of biosynthetic intermediates and citrate on the phenyllactic and hydroxyphenyllactic acids production by *Lactobacillus plantarum* CRL 778. *Journal of Applied Microbiology* 111:1447–1455.

[68] Mansour S, Beckerich JM & Bonnarme P (2008) Lactate and amino acid catabolism in the cheese-ripening yeast *Yarrowia lipolytica*. *Applied Environmental Microbiology*. 74: 6505–6512.

[69] Mu W, Yu S, Zhu L, Jiang B & Zhang T (2012) Production of 3-phenyllactic acid and 4-hydroxyphenyllactic acid by *Pediococcus acidilactici* DSM 20284 fermentation. *European Food Research & Technology* 235: 581–585.

[70] Hummel W, Schütte H & Kula M-R (1985) d-2-Hydroxyisocaproate dehydrogenase from *Lactobacillus casei.* A new enzyme for stereospecific reduction of 2-ketocarboylic acid. *Applied Microbiology & Biotechnology* 21: 7-15.

[71] Wada Y, Iwai S, Tamura Y, Ando T, Shinoda T, Arai K & Taguchi H (2008) A new family of D-2-hydroxyacid dehydrogenases that comprises D-mandelate dehydrogenases and 2-ketopantoate reductases. Bioscience, Biotechnology & Biochemistry 72: 1087–1094.

[72] Hummel W, Schütte H & Kula M-R (1988) d-(-)-Mandelic acid dehydrogenase from *Lactobacillus curvatus*. *Applied Microbiology & Biotechnology* 28: 433–439.

[73] Tuberoso CIG, Bifulco E, Caboni P, Sarais G, Cottiglia F, Floris I. Lumichrome and phenyllactic acid as chemical markers of thistle (Galactites tomentosa Moench) honey. *Journal of Agricultural & Food Chemistry* 2011;59:364–9.

[74] Tan ST, Wilkins AL, Molan PC, Holland PT, Reid M. A chemical approach to the determination of floral sources of New Zealand honeys. *Journal of Apicultural Research* 1989;28:212–22.

[75] Dimitrova B, Gevrenova R, Anklam E. Analysis of phenolic acids in honeys of different floral origin by solid-phase extraction and high-performance liquid chromatography. *Phytochemical Analysis* 2007;18:24–32.

[76] Wang JP, Yoo JS, Lee JH, Zhou TX, Jang HD, Kim HJ, et al. Effects of phenyllactic acid on production performance, egg quality parameters, and blood characteristics in laying hens. *Journal of Applied Poultry Research* 2009;18:203–9.

[77] Wang JP, Lee JH, Yoo JS, Cho JH, Kim HJ, Kim IH. Effects of phenyllactic acid on growth performance, intestinal microbiota, relative organ weight, blood characteristics, and meat quality of broiler chicks. *Poultry Sciences* 2010;89:1549–55.

[78] Wang JP, Yoo JS, Lee JH, Jang HD, Kim HJ, Shin SO, et al. Effects of phenyllactic acid on growth performance, nutrient digestibility, microbial shedding, and blood profile in pigs. *Journal of Animal Sciences* 2009;87:3235–43.

[79] Wang J, Shao Y, Zhang Y, Jiao B, Dai H, Xue F. Experimental studies of β-phenyllactic acid on the coronary system. *Journal of Shanghai Medical University* 1991;18:295 – 297.

[80] Scott EJV, Yu RJ. Method of using 3-phenyllactic acid for treating wrinkles. U.S. Patent US5643953 A, 1997.

[81] Narayanan TK, Rao GR. Beta-indoleethanol and beta-indolelactic acid production by *Candida* species: their antibacterial and autoantibiotic action. *Antimicrobial Agents & Chemotherapy* 1976;9:375–80.

[82] Aragozzini F, Ferrari A, Pacini N, Gualandris R. Indole-3-lactic acid as a tryptophan metabolite produced by *Bifidobacterium* spp. *Applied Environmental Microbiology* 1979;38:544–6.

[83] Frankenberger WT, Poth M. L-tryptophan transaminase of a bacterium isolated from the rhizosphere of *Festuca octoflora* (graminae). *Soil Biology & Biochemistry* 1988;20:299–304.

[84] Gao S, Oh DH, Broadbent JR, Johnson ME, Weimer BC, Steele JL. Aromatic amino acid catabolism by lactococci Catabolisme des acides aminés aromatiques des lactocoques. *Le Lait* 1997;77:11.

[85] El Soda MA. The role of lactic acid bacteria in accelerated cheese ripening. *FEMS Microbiology Reviews* 1993;12:239–51.

[86] Gummalla S, Broadbent JR. Tryptophan catabolism by *Lactobacillus casei* and *Lactobacillus helveticus* cheese flavor adjuncts. *Journal of Dairy Sciences* 1999;82:2070–7.

[87] Berrah G, Konetzka WA. Selective and reversible inhibition of the synthesis of bacterial deoxyribonucleic acid by phenethyl alcohol. *Journal of Bacteriology* 1962;83:738–44.

[88] Woodley CL, Baldwin JN, Greenberg J. Nitrosoguanidine sequential mutagenesis mapping of *Mycobacterium tuberculosis* genes. *Journal of Bacteriology* 1981;147:176–80.

[89] Lucchini JJ, Bonnaveiro N, Cremieux A, Le Goffic F. Mechanism of bactericidal action of phenethyl alcohol in *Escherichia coli. Current Microbiology* 1993;27:295–300.

[90] Ingram LO, Buttke TM. Effects of alcohols on micro-organisms. *Advanced Microbiology & Physiology* 1984;25:253–300.

[91] Lilley BD, Brewer JH. The selective antibacterial action of phenylethyl alcohol. *Journal of American Pharmaceutical Association* 1953;42:6–8.

[92] Fabre CE, Blanc PJ, Goma G. 2-Phenylethyl alcohol: an aroma profile. *Perfum Flavorist* 1998;23:43–5.

[93] Etschmann M, Bluemke W, Sell D, Schrader J. Biotechnological production of 2-phenylethanol. *Applied Microbiology & Biotechnology* 2002;59:1–8.

[94] Fabre CE, Blanc PJ, Goma G. Production of 2-phenylethyl alcohol by *Kluyveromyces marxianus. Biotechnology Progress* 1998;14:270–4.

[95] Clark G. Phenethyl alcohol. *Perfume Flavor* 1990;15:37–44.

[96] Gassenmeier K, Schieberle P. Potent aromatic compounds in the crumb of wheat bread (French-type) — influence of pre-ferments and studies on the formation of key odorants during dough processing. *Zeitschrift fuer Lebensmittel-Untersuchung und -Forschung* 1995;201:241–8.

[97] Kieser M, Pollard A, Stevens P, Tucknott O. Determination of 2-phenylethanol in cider. *Nature* 1964;204:887.

[98] Aoki T, Uchida K. Enhanced formation of 2-phenylethanol in *Zygosaccharomyces rouxii* due to prephenate dehydrogenase deficiency. *Agricultural Biology & Chemistry* 1990;54:273–4.

[99] Mo EK, Sung CK. Phenylethyl alcohol (PEA) application slows fungal growth and maintains aroma in strawberry. *Postharvest Biology & Technology* 2007;45:234–9.

[100] Zhang M, Pan Q, Yan G, Duan C. Using headspace solid phase micro-extraction for analysis of aromatic compounds during alcoholic fermentation of red wine. *Food Chemistry* 2011;125:743–9.

[101] Pachlová V, Buňka F, Chromečková M, Buňková L, Barták P, Pospíšil P. The development of free amino acids and volatile compounds in cheese "Oloumoucké tvarůžky" (PGI) during ripening. *International Journal of Food Sciences & Technology* 2013; 48:91868-1876

[102] Jollivet N, Chataud J, Vayssier Y, Bensoussan M, Belin JM. Production of volatile compounds in model milk and cheese media by eight strains of *Geotrichum Candidum* Link. *Journal of Dairy Research* 1994;61:241–8.

[103] Lingappa BT, Prasad M, Lingappa Y, Hunt DF, Biemann K. Phenethyl alcohol and tryptophol: Autoantibiotics produced by the fungus *Candida albicans*. *Science* 1969;163:192–4.
[104] Gañan M, Martínez-Rodríguez AJ, Carrascosa AV. Antimicrobial activity of phenolic compounds of wine against *Campylobacter jejuni*. *Food Control* 2009;20:739–42.
[105] Cueva C, Mingo S, Muñoz-González I, Bustos I, Requena T, del Campo R, et al. Antibacterial activity of wine phenolic compounds and oenological extracts against potential respiratory pathogens. *Letters in Applied Microbiology* 2012;54:557–63.
[106] Crowley S, Mahony J, van Sinderen D. Comparative analysis of two antifungal *Lactobacillus plantarum* isolates and their application as bioprotectants in refrigerated foods. *Journal of Applied Microbiology* 2012;113:1417–27.
[107] Niku-Paavola M-L, Laitila A, Mattila-Sandholm T, Haikara A. New types of antimicrobial compounds produced by *Lactobacillus plantarum*. *Journal of Applied Microbiology* 1999;86:29–35.
[108] Chipley J. Sodium benzoate and benzoic acid. In: *Antimicrobial Food* Michael Davidson P, Sofos J, Branen A, editors.Third Ed., vol. 20052146, CRC Press; 2005, p. 11–48.
[109] Nambou K, Gao C, Zhou F, Guo B, Ai L, Wu ZJ. A novel approach of direct formulation of defined starter cultures for different Kefir-like beverage production. *International Dairy Journal* 2013. In Press.
[110] Wu C, Liu R, Huang W, Rayas-Duarte P, Wang F, Yao Y. Effect of sourdough fermentation on the quality of Chinese Northern-style steamed breads. *Journal of Cereal Sciences* 2012;56:127–33.
[111] Groot MNN, Bont JAM de. Conversion of phenylalanine to benzaldehyde initiated by an aminotransferase in *Lactobacillus plantarum*. *Applied Environmental Microbiology* 1998;64:3009–13.
[112] Saavedra MJ, Borges A, Dias C, Aires A, Bennett RN, Rosa ES, et al. Antimicrobial activity of phenolics and glucosinolate hydrolysis products and their synergy with streptomycin against pathogenic bacteria. *Medical Chemistry* 2010;6:174–83.
[113] Tolonen M, Rajaniemi S, Pihlava JM, Johansson T, Saris PE., Ryhänen EL. Formation of nisin, plant-derived biomolecules and antimicrobial activity in starter culture fermentations of Sauerkraut. *Food Microbiology* 2004;21:167–79.
[114] Kyung KH, Fleming HP. Antimicrobial activity of sulfur compounds derived from cabbage. *Journal of Food Protection* 1997;60:67–71.
[115] Somers E, Ptacek D, Gysegom P, Srinivasan M, Vanderleyden J. *Azospirillum brasilense* produces the auxin-like phenylacetic acid by using the key enzyme for indole-3-acetic acid biosynthesis. *Applied Environmental Microbiology* 2005;71:1803–10.
[116] Adams MR, Nicolaides L. Review of the sensitivity of different foodborne pathogens to fermentation. *Food Control* 1997;8:227–39.

