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Review

Bioconversion Using Lactic Acid Bacteria: Ginsenosides, GABA, and Phenolic Compounds

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Lactic acid bacteria (LAB) are used as fermentation starters in vegetable and dairy products and influence the pH and flavors of foods. For many centuries, LAB have been used to manufacture fermented foods; therefore, they are generally regarded as safe. LAB produce various substances, such as lactic acid, β-glucosidase, and β-galactosidase, making them useful as fermentation starters. Existing functional substances have been assessed as fermentation substrates for better component bioavailability or other functions. Representative materials that were bioconverted using LAB have been reported and include minor ginsenosides, γ-aminobutyric acid, equol, aglycones, bioactive isoflavones, genistein, and daidzein, among others. Fermentation mainly involves polyphenol and polysaccharide substrates and is conducted using bacterial strains such as *Streptococcus thermophilus*, *Lactobacillus plantarum*, and *Bifidobacterium* sp. In this review, we summarize recent studies of bioconversion using LAB and discuss future directions for this field.

Keywords: Lactic acid bacteria, fermentation, bioconversion, phenolic compound, β-glucosidase

Introduction

Consumers have become increasingly concerned about healthy and functional foods. The health-food industry has attempted to identify new materials or utilize existing materials in new ways. Intestinal bacteria are involved in metabolic pathways and can influence host health [1, 2]. Lactic acid bacteria (LAB) are present in fermented foods, such as vegetables (kimchi and sauerkraut) and dairy products (yogurt and cheese); therefore, they are generally regarded as safe. Some LAB have probiotic characteristics, including maintenance of intestinal microflora, and antioxidant, anti-allergy, and anticancer properties, and their use has increased with the goal of improving health or nutrition [1, 2]. Probiotic strains can be damaged by exposure to simulated gastric conditions; however, some LAB isolated from fermented foods have a high survival rate under harsh conditions [1].

Traditional starter cultures used in the food industry are selected for their ability to rapidly produce desirable organoleptic qualities; however, probiotic bacteria should be selected for their potential nutritional benefits. Traditional yogurt starter cultures include *Streptococcus thermophilus* and *Lactobacillus delbrueckii* sp. *bulgaricus*. Currently, a number of dairy products are marketed as containing probiotic bacteria such as *L. acidophilus* or *Bifidobacterium* species. Fermented tea containing LAB is thought to have enhanced flavor and phenolic compound bioavailability through decreased contents of epigallocatechin gallate, epigallocatechin, and epicatechin [3]. Tea fermented using microorganism-derived enzymes has been investigated for digestibility, anticancer effects, and prevention and treatment of cardiovascular disease [3−7].

The bioavailability of glucosides is increased by hydrolysis of the sugar moiety using β-glucosidase [8]. The water solubility and chemical stability of aglycone forms make them effective for detoxifying endogenous metabolites and xenobiotics, including defense against mycotoxins [4, 9]. β-Glucosidase removes glucopyranosyl residues from the non-reducing end of β-glucoside by catalyzing the hydrolysis of the glycosidic bond [10]. β-Glucosidases are known to be widely distributed among animals, plants, fungi, yeasts, and bacteria [11]. As producer strains, β-glucosidases have been reported in *L. acidophilus*, *L. delbrueckii* subsp. *bulgaricus*, *L. casei*, *L. plantarum* [12], *L. fermentum*, and several *Bifidobacterium* sp. [5]. Most β-glucosidases can hydrolyze a broad range of substrates; however, their huge diversity makes it difficult to predict their aglycone specificity [13].

In this review, we summarize recent studies of bioconversion of representative substances using LAB. The roles of ginsenosides, γ-aminobutyric acid (GABA), hydroxytyrosol, isoflavones, and phenolic compounds in fermentation are considered. Additionally, the direction of future studies is discussed.

Bioconversion of Ginseng or Ginsenoside Using LAB

Definition and Classification of Ginseng

Ginseng (*Panax ginseng* C.A. Mayer) is a well-known medicinal plant in China, Korea, Japan, and other Asian countries [14, 15]. The major active ingredients of ginseng are ginsenosides, whose functions depend on the molecule type [16−18]. Major ginsenosides have multiple sugar moieties and are hardly absorbed by the human body [15]. The major ginsenosides are glycosides that contain an aglycone with tetracyclic triterpene, and include ginsenosides Rb1, Rb2, Rc, and Rd, and protopanaxatriol-types such as Re and Rg1, which comprise more than 90% of total ginsenosides. Major ginsenosides can be converted into deglycosylated ginsenosides and minor ginsenosides such as F2, compound K (C-K), compound Mc, compound Y, Rg3, Rg2, Rh2, Rh1, and F1. Minor ginsenosides have more effective pharmacological properties than major ginsenosides, and can be bioconverted using heat, enzymes, and microorganisms.

Biofunctional Effects of Ginseng

Ginseng has various biofunctional effects on liver, bone, and brain health in humans. Ginsenosides Rb1, Rb2, and Rb3 influence liver health [19], the immune system [20], and anti-inflammatory functions [18, 21], respectively. Rb1 attenuated plasma aminotransferase activities and liver inflammation to inhibit CCl_4-induced liver fibrosis in rats [19]. Rb2 prevented the lethal infection of the hemagglutinating virus of Japan (HCJ) in mice [20]. Ginsenosides Rg1, Rg2, and Rg3 are involved in bone health [22], neuroprotection [23], and vascular function modulation [24], respectively. In addition, mixtures of Rg1 and Rg2 improve cognitive function through their effects on brain metabolic pathways [25]. Rh1 and Rh2 were reported to have anti-inflammatory effects [26, 27]. Rh2 produces anticancer [28, 29] and antidiabetic effects by affecting the secretion of insulin [30, 31].

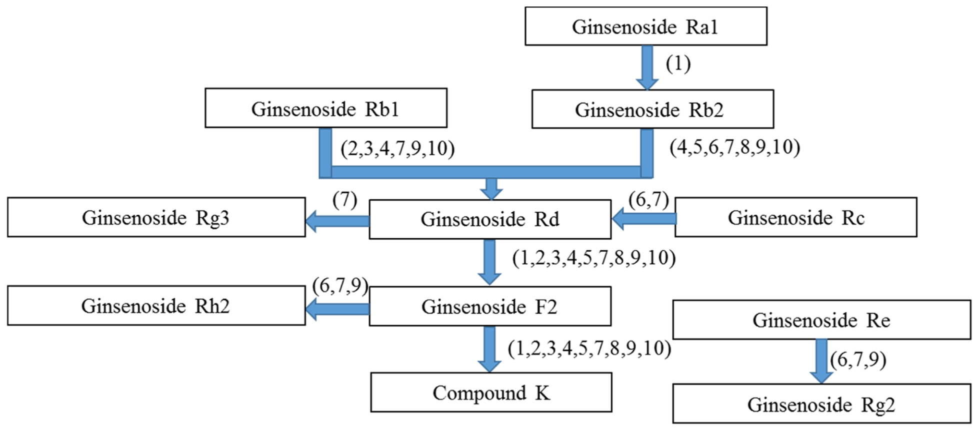
Bioconversion of Ginsenosides by Enzymes and Microbial Fermentation

The production of the minor ginsenosides Rh1, Rh2, C-K, Rg2, and F2 from major ginsenosides has been evaluated previously (Fig. 1). Ginsenosides Rb1, Rb2, and Rc can be transformed to C-K by human intestinal microorganisms [32], and C-K has been shown to have anticancer effects in tumor cell lines [33]. The efficacy of ginseng depends on the host's intestinal condition, and therefore bioconversion is necessary for specific ginsenoside compounds. *L. rossiae* DC05, isolated using esculin-MRS agar, was used for bioconversion of the major ginsenosides Rb1 and Re to C-K and Rg2 [34]. *Leuconostoc mesenteroides* LH1 isolated from kimchi was used to produce β-glucosidase, and to convert Rb1 to Rd, F2, and C-K [35]. The optimum conditions for conversion of Rb1 to C-K were pH 6.0, 30°C, and 72 h. Several recombinant technologies have applied *Bifidobacterium* strains to the production of ginsenoside aglycones [36, 37]. These bioconversion reactions are used to produce microbial crude enzymes whose mechanisms depend on the bacterial strain. Lee *et al*. [38] reported changes in ginsenoside composition during fermentation of mixed cultures including *Saccharomyces cerevisiae*, *L. acidophilus*, *L. plantarum*, *L. brevis*, and *Bacillus subtilis*. In addition, Jung *et al*. [39] conducted microbial fermentation of yogurt fortified with red ginseng extract.

Bioconversion of Sodium Glutamate to γ-Polyglutamic Acid (γ-PGA) and GABA

Characteristics, Function, and Synthesis of γ-PGA and GABA

PGA has been used as an implantable biomaterial for hydrogel formation because of its biodegradable, non-toxic, and non-immunogenic properties [41, 42]. GABA is a nonprotein amino acid and the major inhibitory neurotransmitter of the central nervous system. GABA has antianxiety, antidepressant, and antihypertensive activities and regulates hormone secretion [43, 44]. GABA is widely distributed in mammals and plants, but its content under natural conditions is low. Therefore, γ-PGA and GABA are produced by chemical synthesis or bioconversion methods developed using microorganisms [45−47]. Various microorganisms have been reported for GABA and γ-PGA production, including *Bacillus* sp., *Escherichia coli*, *Aspergillus* sp., and LAB (Table 1) [43, 48, 49].



*** Microbial enzyme (Used microorganism; optimized condition)**
(1) *B. breve* K-110; 45°C, pH 6.0 [34]
(2) *Leu. citreum* LH1; 30°C, pH 6.0, 72 h [35]
(3) *L. rossiae* DC05; 30°C, pH 7.0 [34]
(4) *L. rhamnosus* GG; 40°C, pH 6.0 [40]
(5) *Bifidobacterium* sp. Int57, *Bifidobacterium* sp. SJ32 [75, 76]
(6) *L. delbrueckii* [74, 75]
(7) *B. longum* RD47; 40°C, pH 5.0 and 7.0 [72]
(8) *L. pentosus* DC101; 30°C, pH 7.0, 72 h [73]

*** Microbial fermentation**
(4) *L. rhamnosus* GG; mixture of ginseng bacterial suspension (19:1), 40°C, 48 or 96 h [40]
(9) Mixed culture of *B. minimum* KK-1 and *B. cholerium* KK-2 [33] (0.5 mg ginsenoside with 250 mg bacterial suspension, 37°C, 20 h)
(10) Mixed culture of *Saccharomyces cerevisiae*, *L. acidophilus*, *L. plantarum*, *L. brevis*, and *Bacillus subtilis*; 6 L water + 300 g red ginseng [38]

Fig. 1. Metabolic pathway of ginsenoside bioconversion using enzymes and microbial fermentation.
B., *Bifidobacterium*; *Leu.*, *Leuconostoc*; *L.*, *Lactobacillus*; Rb1, 3-*O*-[β-D-glucopyranosyl-(1-2)-β-D-glucopyranosyl]-20-*O*-[β-D-glucopyranosyl-(1-6)-β-D-glucopyranosyl]-20(S)-protopanaxadiol; Rb2, 3-*O*-[β-D-glucopyranosyl-(1-2)-β-D-glucopyranosyl]-20-*O*-[α-L-arabinopyranosyl-(1-6)-β-D-glucopyranosyl]-20(S)-protopanaxadiol; Rc, 3-*O*-[β-D-glucopyranosyl-(1-2)-β-D-glucopyranosyl]-20-*O*-[α-L-arabinofuranosyl-(1-6)-β-D-glucopyranosyl-]-20(S)-protopanaxadiol; Rd, 3-*O*-[β-D-glucopyranosyl-(1-2)-β-D-glucopyranosyl]-20-*O*-β-D-glucopyranosyl-20(S)-protopanaxadiol; F2, 3-*O*-β-D-glucopyranosyl-20-*O*-β-D-glucopyranosyl-20(S)-protopanaxadiol; Compound K, 20-*O*-β-D-glucopyranosyl-20(*S*)-protopanaxadiol; Rh2, 3-*O*-β-D-glucopyranosyl-20(*S*)-protopanaxadiol; Rg2, 6-*O*-[α-L-rhamnopyranosyl-(1-2)-β-D-glucopyranosyl-20(*S*)-protopanaxatriol; Rg3, 3-*O*-[β-D-glucopyranosyl-(1-2)-β-D-glucopyranosyl]-20(S)-protopanaxadiol.

Bioconversion of Sodium Glutamate to γ-PGA and GABA

Serial coculturing of *B. subtilis* HA and *L. plantarum* K154 produced 0.86% GABA from sodium glutamate [42]. *Bacillus* sp. SW1-2 and *B. licheniformis* produced 12.64 and 75 g/l of γ-PGA from L-glutamic acid, respectively. *B. subtilis* HA produced 22.5 g/l of γ-PGA from soybeans. The decrease in pH during LAB fermentation may be related to the microbial conversion of glutamate to GABA [50]. *L. brevis*, isolated from Korean kimchi using gas release and HPLC methods, reportedly produced 17.7–25.8 g/l of GABA with the addition of 70 g/l glutamic acid after a 72 h incubation time [51]. Skim milk fermented by *L. helveticus* ND01 showed angiotensin-converting enzyme (ACE) inhibitory effects and GABA production [47]. The production of GABA was increased with increasing incubation time, reaching 165.11 mg/l at 30 h. A correlation was observed between the ACE inhibitory activity and GABA content with free amino acid content in fermented milk and soymilk (r = 0.94, p < 0.05). Milk was fermented by *L. plantarum* PU11 and *Lactococcus lactis* DIBCA2 [48]; after fermentation, the milk showed a cell density of 8.0 log CFU/ml and GABA production of 144.5 mg/kg.

Bioconversion of Oleuropein to Hydroxytyrosol Using LAB

Characteristics, Function, and Synthesis of Oleuropein and Hydroxytyrosol

Oleuropein is the most important phenolic compound in olives [52]. However, this phenolic glucoside is responsible for the bitterness of unprocessed olives, and an *L. plantarum* strain has been used to reduce this bitterness [4]. Oleuropein has been shown to have antioxidant, anti-inflammatory, anticancer, anti-atherogenic, antiviral, antimicrobial, hypolipidemic, and hypoglycemic effects [52]. Oleuropein can be converted to hydroxytyrosol by β-glucosidase and esterase [53]. *L. pentosus*, *L. brevis*, and *Pediococcus pentosaceus* were isolated from fermented olives and were found to produce β-glucosidase [54]. Hydroxytyrosol has shown interesting biological properties, such as antioxidant,

Table 1. Bioconversion of sodium glutamate using LAB.

Bioconversion[a] (substrate → product)	LAB strains	Characteristics
Sodium glutamate → γ-PGA and GABA	*Lactobacillus plantarum* K154 and *Bacillus subtilis* HA	Serial fermentation: first fermentation using *Bacillus subtilis* HA/ mixed fermentation using two strains/2nd fermentation with skim milk using *Lactobacillus plantarum* K154 [42]
Sodium glutamate → GABA	*Lactobacillus brevis* NCL912	Screening in MRS medium with 1% sodium glutamate, pH 5.0 [77]
MSG → GABA	*Lactobacillus brevis* NPS-QW-145	Prescreening method using MSG and pH control [51]
	Lactobacillus brevis TCCC 13007	Two-step biotransformation; growing and resting cells [49]
	Lactobacillus brevis K203	Optimization and purification [78]
	Lactobacillus brevis DPC6108	Potential bioconversion in intestinal condition [79]
Glutamate → GABA	*Lactobacillus plantarum* DSM19463	Application in grape must; skin protection [50]
	Lactobacillus plantarum PU11	ACE inhibitory effect and GABA production of fermented milk [48]
Skim milk → GABA	*Lactobacillus helveticus* ND01	ACE inhibitory effect and GABA production of fermented milk [47]
White wheat, wholemeal wheat, and rye flours → GABA	*Lactobacillus plantarum* C48 *Lactococcus lactis* subsp. *lactis* PU1	Application in sour dough [46]

[a]MSG, monosodium glutamate; γ-PGA, γ-polyglutamic acid; GABA, γ-aminobutyric acid.

antibacterial, and free-radical scavenging activities, that were higher than those of oleuropein [53].

Bioconversion of Oleuropein to Hydroxytyrosol

Table 2 shows the bioconversion of oleuropein using LAB. Ciafardini *et al*. [55] and Marsilio *et al*. [56] reported that *L. plantarum* strains degraded oleuropein in olive fruit. *L. plantarum* initially hydrolyzes oleuropein through its β-glucosidase action to produce its aglycone form. In the second step, the esterase activity of *L. plantarum* gives rise to hydroxytyrosol and elenolic acid. β-Glucosidase activity is partially inhibited by glucose; however, esterase activity in the second step of biodegradation is not influenced by glucose [57]. *L. plantarum* 6907, *L. paracasei* 9192, *L. casei*, *Bif. lactis* BO, *Enterococcus faecium* 32, and *L. acidophilus* strain LAFTI®L10 were tested for their ability to convert oleuropein byproducts in olives and olive oil into hydroxytyrosol [53]. Of these strains, *L. plantarum* 6907, due to its auxotrophic characteristics, was the most effective with a hydroxytyrosol yield of 30%.

Bioconversion of Isoflavones Using LAB

Characteristics, Function, and Synthesis of Isoflavones and Aglycone Isoflavones

Isoflavones are estrogen-like compounds found in legumes. Isoflavones have shown biological activities for the prevention and therapy of hormone-related diseases, cardiovascular diseases, breast, prostate, and colon cancers, and menopausal symptoms [58, 59]. Daidzein and genistein are the most widely studied isoflavones. Daidzein can be metabolized to produce equol ((3*S*)-3-(4-hydroxyphenyl)-7-chromanol) by intestinal bacteria in only 30–40% of the human population [58]. Equol has stronger estrogenic activity than daidzein and *O*-desmethylangolensin [59]. The beneficial effects of isoflavones depend on host health; therefore, bioconversion of isoflavones has been in steady demand (Table 3).

Table 2. Bioconversion of oleuropein using LAB.

Bioconversion (substrate → product)	LAB strains	Characteristics
Oleuropein → hydroxytyrosol	*Lactobacillus plantarum* 6907 and *Lactobacillus paracasei* 9192	Hydrolysis reaction; comparison of aerobic and anaerobic conditions [53]
	Lactobacillus plantarum (B17, B20, and B21)	β-Glucosidase production; stable in pH 3.5 and 8% NaCl [55]
Oleuropein/5-bromo-4-chloro-3-indolyl β-D-glucuronide → hydroxytyrosol	*Lactobacillus plantarum*, *Lactobacillus pentosus*, *Lactobacillus brevis*, and *Pediococcus pentosaceus*	β-Glucosidase production [54]
Oleuropein → oleuropein-aglycone → hydroxytyrosol + elenolic acid	*Lactobacillus plantarum* B21	Table olive debittering; β-glucosidase and esterase production [56, 57]

Table 3. Bioconversion of isoflavone glycosides using LAB.

Bioconversion (substrate → product)	LAB strains	Characteristics
Black soymilk (isoflavone glycosides daidzein and genistein)	*Streptococcus thermophilus* S10	Health functional fermented black soymilk having antioxidant activity [63]
Brain heart infusion medium with daidzein (daidzein → equol)	*Bifidobacterium breve* ATCC 15700 and *Bifidobacterium longum* BB536	Potential probiotic strains with function of equol [62]
Soymilk-tea (isoflavone glycoside → aglycone)	*Streptococcus thermophilus* ASCC 1275; *Lactobacillus bulgaricus* ASCC 859; *Lactobacillus acidophilus* CSCC 279	Probiotic characteristics and bioconversion rate [45]
Soya bean (isoflavone glycoside → aglycone)	*Lactobacillus acidophilus* B4496; *Lactobacillus bulgaricus* CFR2028; *Lactobacillus casei* B1922; *Lactobacillus plantarum* B4495; *Lactobacillus fermentum* B4655 with *Saccharomyces boulardii*	Fermentation of probiotic LAB with yeast; improvement of the bioavailability of isoflavone, mineral, and vitamin B complex [66]
Biotin-supplemented soymilk (isoflavone → isoflavone aglycone)	*Lactobacillus fermentum* BT 8633	Ultrasound treatment; increment of permeabilization in the membrane of treated cells [65]
Soy milks (isoflavone → isoflavone aglycone (equol))	Mixed culture of *Lactobacillus plantarum* DPPMASL33; DPPMA 24W; *Lactobacillus rhamnosus* DPPMAAZ1; *Lactobacillus fermentum* DPPMA114	Manufacture of soy milk using commercial soy flour; immunomodulatory effect on intestinal human Caco-2/TC7 cells [64]

Bioconversion of Isoflavones to Aglycone Forms

Equol producers among LAB include *Lactococcus garvieae* strain 20-92 [59, 60], *Bif. animalis*, *Bif. longum*-a, *Bif. pseudolongum* [61], *Bif. breve* 15700, *Bif. longum* BB536 [62], and *Lactobacillus* sp. Niu-O16 [60]. Soymilk fermented with *L. plantarum* TWK10 was found to improve nutritional and bioactive properties of foods [8]. β-Glucosidase increases the aglycone isoflavone content and suppresses tyrosinase activity and melanin production. Black soymilk fermented with *S. thermophilus* S10 converted daidzin and genistin to daidzein and genistein [63]. Total phenol contents, DPPH radical scavenging activity, and reducing power were increased during fermentation. A mixed culture of *L. plantarum* (DPPMA24W and DPPMASL33), *L. fermentum* DPPMA114, and *L. rhamnosus* DPPMAAZ1 was selected for its β-glucosidase activity, and these strains were incubated in soymilk for 96 h. After fermentation, daidzein, genistein, glycitein, and equol were produced; anti-inflammatory effects of these compounds were observed on nitric oxide and IL-8 production in intestinal human Caco-2/TC7 cells [64]. Ultrasound of *L. fermentum* BT8633 affected β-glucosidase production and increased the bioconversion of isoflavones to aglycone forms in biotin-supplemented soymilk [65]; ultrasound may temporarily permeabilize the membrane of treated cells. *L. acidophilus* B4496, *L. bulgaricus* CFR2028, *L. casei* B1922, *L. plantarum* B4495, and *L. fermentum* B4655 were used with *Saccharomyces boulardii* to ferment soymilk to obtain the bioactive isoflavones genistein and daidzein [66].

Bioconversion of Other Phenolic Compounds

Characterization of Phenolic Compounds

Phenolic compounds are important constituents of food products of plant origin, and these compounds are directly related to the sensory characteristics of foods, such as flavor, stringency, and color. Phenolic compounds are beneficial to health because of their activities against carcinogenesis and mutagenesis, mainly through antioxidant effects [8, 67, 68]. Medicinal and tea plants reported to have functional components include *Magnolia*, *Cudrania tricuspidata* (Carr.) Bureau [69], and *Inula britannica* [70]. Various phenolic compounds from these plants can be converted to aglycone forms, which are more bioactive and have more potent antioxidant and anticancer activities, among other effects (Table 4).

Bioconversion of Phenolic Compounds to Aglycone Forms

A representative anthocyanin (malvidin-3-*O*-glucoside) was extracted from Pinot Noir grape skins and fermented with *L. plantarum* WCFS1 [68]. The main metabolites were gallic acid and protocatechuic acid, and increased antioxidant activity was observed. *Magnolia* flower petal extract was fermented by *Pediococcus acidilactici* KCCM 11614; fermentation increased the total phenolic contents, total flavonoids, and antioxidative and anticancer activities [67]. *C. tricuspidata* (Carr.) Bureau leaves were fermented with *Lactobacillus* derived from Korean soybean paste [68]; flavonoid glycosides were converted to flavonols, quercetin,

Table 4. Bioconversion of phenolic compounds using LAB.

Mechanisms[a] (substrate → product)	LAB strains	Characteristics
Green tea (EGCG, EGC, and EC → GCG and GC)	*Lactobacillus plantarum* 62901 and *Leuconostoc pseudomesenteroides* K200132	Decrement of grass flavor and bitter taste [3]
Magnolia flower petal extract	*Pediococcus acidilactici* KCCM 11614	Increment of antioxidative and anticancer activities [67]
Pinot Noir (anthocyanin glycoside → phenolic acid such as gallic acid and protocatechuic acid)	*Lactobacillus plantarum* WCFS1	Application in the human digestive system; antioxidant activity [68]
Cudrania tricuspidata leaves (flavonoid glycoside flavonols, quercetin, and kaempferol)	*Lactobacillus plantarum* SDL1413	Fermentation in 10% plant powder; antioxidant effect and identification through LC-MS [69]
Inula britannica extract	*Lactobacillus acidophilus*, *Bifidobacterium longum*, and *Streptococcus thermophilus* (ABTL)	Application in Cheddar-type cheese; antioxidant activity [70]

[a]EGCG, epigallocatechin gallate; EGC, epigallocatechin; EC, epicatechin; GCG, gallocatechin gallate; GC, gallocatechin.

and kaempferol. *S. thermophilus* ASCC 1275, *L. acidophilus* CSCC 2400, *L. paracasei* CSCC 279, and *L. delbrueckii* ssp. *bulgaricus* ATCC 859 converted isoflavone glycosides to aglycones in soymilk containing tea extract [45]. *L. acidophilus* CSCC 2400 showed the highest activity with a bioconversion ratio of 67–78%, resulting from the production of β-glucosidase and β-galactosidase. Extracts from green, oolong, and black teas influenced the cell population and production of bacterial enzymes in soymilk supplemented with them. After addition of *I. britannica* extract containing quercetin to yogurt strains (*S. thermophilus*, *L. acidophilus*, and *Bif. longum*), Cheddar-type cheese showed increment of total phenolic contents and antioxidant activity [70].

Microbial Fermentation of LAB for Bioconversion

Fermentation of LAB for bioconversion should involve an appropriate bacterial strain and fermentation medium. First, a bacterial strain for enzyme production using *p*-nitrophenyl-β-D-glucopyranoside (*p*NPG) substrate should be selected. These bacterial strains have been screened, mainly in fermented foods of plant origin, for safety and survival. *L. plantarum* is the most frequently used commercial starter in food fermentation [53]. Fermentation media should (i) include natural substances such as soymilk [8, 45, 63, 64, 66], olive [55], or *Magnolia* flower petal extract [67], (ii) contain added natural substrates in MRS medium [49, 51, 56], and (iii) contain added galactose [71], cellobiose [40], or ascorbic acid [72] in MRS medium for enzyme production. The strains *Bif. longum*, *L. plantarum*, *L. pentosus*, *L. brevis*, *L. fermentum*, and *L. mesenteroides* [5, 39, 50, 62, 71] have been used as fermentation starters to increase flavor and bioavailability; however, bacterial cell growth was inhibited by hydroxytyrosol, oleuropein, and tyrosol, and vanillic, *p*-hydroxybenzoic, sinapic, syringic, protocatechuic, and cinnamic acids at high concentrations [72]. In addition, the concentration of glucose must be controlled in fermentation media to increase the production of glycoside hydrolase from probiotic bacteria. High concentrations of glucose induce increased bacterial cell growth but reduce enzyme induction. To avoid glucose catabolite repression, *L. rhamnosus* GG was cultured in MRS medium containing cellobiose and showed 25-fold higher β-glucosidase productivity [40]. Activities of α-L-arabinofuranosidase and α-L-arabinopyranosidase from *Bif. longum* RD47 were increased with the addition of 2% ascorbic acid [72]. Therefore, the concentration of these materials in the fermentation medium should be controlled to achieve high enzyme induction and avoid inhibition.

Conclusions and Perspectives

The use of LAB to enhance probiotic functions in industrial applications has increased. From a commercial perspective, fermented tea and yogurt are representative uses of LAB. In particular, plant-derived LAB are used as fermentation starters, as these strains show resistance to components such as flavonoids. Various natural substances have different bioactive properties because of their structures. In this regard, bioconversion of natural substances has gained industrial and scientific attention to reveal new functions or enhance nutraceutical properties. However, further improvement of bioconversion should be investigated to identify fermentation starters applicable to various substances and to optimize conditions, such as the ratio of substance to fermentation starter and incubation conditions. In addition, it may be possible to use these strains or enzymes to obtain high value-added compounds with antioxidant, estrogenic, and other effects.

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