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Antioxidant Activity of Promising Probiotic Potential *Lactobacillus Plantarum*: A Review

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Abstract: Oxidative stress is a key factor in chronic illnesses. *Lactobacillus plantarum* is a promising probiotic bacteria with considerable antioxidant capacity by boosting enzymatic defenses, making it a promising candidate for enhancing human health. The aim of this study is to evaluate the antioxidant activity of *L. plantarum* and its potential synergistic effects with other bioactive compounds. From this study, *L. plantarum* exhibits significant antioxidant activity through multiple pathways, including scavenging free radicals and modulating oxidative stress responses. *L. plantarum* might enhance the enzymatic activity such as superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GSH). Furthermore, it scavenges free radicals including DPPH•, ABTS•+, and •OH while lowering malondialdehyde (MDA) levels, therefore preventing lipid peroxidation. Notably, the synergistic effects observed include enhanced free radical neutralization and improved cellular defense mechanisms. *L. plantarum* might be a natural antioxidant source for functional foods and medicinal applications that boost overall health and reduce oxidative stress-related illnesses. Additional research is needed to understand the strain-specific processes, clinical effectiveness, functional food uses, and molecular relationships of *L. plantarum*.

Keywords: *Lactobacillus plantarum*; Probiotic potential; Antioxidant activity; Free radical scavenging; Oxidative stress

1. Introduction

Oxidative stress, induced by an imbalance between reactive oxygen species (ROS) and antioxidant defense mechanisms, has been related to several chronic illnesses, including cardiovascular disease, neurological diseases, and cancer (Bhuia et al., 2025; Aktar et al., 2024a). Antioxidants neutralize free radicals, reducing oxidative damage and preserving cellular homeostasis (Chowdhury et al., 2024). In recent years, probiotics more especially, *Lactobacillus plantarum* have drawn a lot of attention due to their potential antioxidant properties (Wang et al., 2012).

L. plantarum is a lactic acid bacteria (LAB) commonly found in fermented foods, dairy products, and the human gastrointestinal tract. It is known for its ability to survive in harsh conditions, including acidic environments and bile salts, making it a promising probiotic candidate (Zhou et al., 2020). Beyond its well-established health advantages, including boosting gut microbiota and strengthening immunological responses, *L. plantarum* has exhibited high antioxidant activity through different pathways, including enzymatic defense systems, free radical scavenging, and metal ion chelation (Ge et al., 2021).

L. plantarum produces antioxidant enzymes such as superoxide dismutase (SOD), glutathione peroxidase (GSH-Px), and catalase (CAT), which assist with neutralizing ROS (Li et al., 2012; Ferdous et al., 2024a). Furthermore, *L. plantarum* can increase total antioxidant capacity (T-AOC) and suppress lipid peroxidation by lowering malondialdehyde (MDA) levels, preventing cells from oxidative damage (Aktar et al., 2024b; Ferdous et al., 2024b). Studies have demonstrated that various strains of *L. plantarum* isolated from fermented foods and dairy products exhibit varied degrees of antioxidant activity, affected by parameters such as strain specificity, fermentation conditions, and substrate composition (Tang et al., 2017). *L. plantarum* is a well-known probiotic bacterium with multiple pharmacological activities, including antimicrobial (Arena et al., 2016), anti-inflammatory (Wang et al., 2023), antiproliferative (Lee et al., 2014), antiviral

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(Bae et al., 2018), antineoplastic (Elhalik et al., 2024), anti-diabetic (Guo et al., 2020), antidiarrheal (Urdaci et al., 2018), cholesterol-lowering (Nguyen et al., 2007), neuroprotective (Cheon et al., 2021) and immunomodulatory (Meng et al., 2018) effects.

In addition to its well-established probiotic potential, recent studies highlight its antioxidant properties, focusing on recent *in vitro* and *in vivo* studies that highlight its role in reducing oxidative stress. Understanding the antioxidant potential of *L. plantarum* could pave the way for its application in functional foods, nutraceuticals, and therapeutic interventions against oxidative stress-related diseases.

2. Methodology

2.1. Literature search strategy

A comprehensive search was carried out using keywords like Antioxidant, *Lactobacillus plantarum*, and activity/effect, across reliable scientific resources like Google Scholar, PubMed, ScienceDirect, Scopus, and Web of Science, covering the years 2000 –2025. Keywords included "*L. plantarum*," "antioxidant activity," and "mechanisms of action."

2.1.1. Inclusion criteria

The following standards were used to choose the studies: (1) Studies investigating antioxidant effects from a range of sources. (2) *Ex vivo*, *in vitro*, or *in vivo* studies, regardless of the use of experimental animals. (3) Studies that either reveal or conceal details regarding the mode of action.

2.1.2. Exclusion criteria

The following exclusion criteria were applied: (1) Titles and/or abstracts that didn't fit the inclusion criteria or contained duplicate data. (2) Studies on anticancer action while other findings overshadow the focus of the present inquiry.

3. Results and discussion

3.1. Antioxidant activity of *L. plantarum*

Numerous investigations have assessed *L. plantarum*'s antioxidant capacity utilizing a range of strains, sources, and test media. The findings show that *L. plantarum* has strong antioxidant effects via a variety of pathways, such as lipid peroxidation inhibition, radical scavenging, and enzyme upregulation.

3.1.1. Enzymatic antioxidant activity

Multiple strains of *L. plantarum* showed enhanced enzymatic activity of major antioxidant enzymes such as SOD, GSH-Px, CAT, and T-AOC. For instance, *L. plantarum* C88 and C10 isolated from fermented dairy product tofu significantly enhanced SOD, GSH-Px, and T-AOC while reduced MDA, hydroxyl radicals (•OH), 2, 2-diphenyl-1-picrylhydrazyl (DPPH) radicals (DPPH•), and 2, 2′-casino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) free radical (ABTS•+) (Li et al., 2012). Similarly, *L. plantarum* NJAU-01 collected from Jinhua ham increased SOD, GSH-Px, CAT, and T-AOC, demonstrating protective effects against oxidative stress in Kunming mice (Ge et al., 2021). The overexpression of these enzymes indicates an effective antioxidative defense system that decreases oxidative damage.

3.1.2. Radical scavenging activity

Many *L. plantarum* strains exhibited effective DPPH and ABTS radical scavenging activities against DPPH•, ABTS•+, and •OH. *L. plantarum* JLAU103 and CNPC003 demonstrated increased ferric-reducing antioxidant power (FRAP) while reducing ABTS•+ and DPPH• (Min et al., 2019; Bomfim et al., 2020). Moreover, *L. plantarum* DM5 and MA2 exhibited enhanced SOD and GSH-Px activity, as well as substantial reductions in hydroxyl radicals, ferrous ions (Fe^{2+}), and lipid peroxidation indicators (Das & Goyal, 2015; Tang et al., 2017). These findings suggest that *L. plantarum* helps to reduce oxidative stress by radical neutralization (**Table 1**).

3.1.3. Lipid peroxidation and inhibition of oxidative damage

Multiple investigations showed that *L. plantarum* can minimize lipid peroxidation. *L. plantarum* strains such as FC225, ZLP001, and 120 substantially lowered MDA levels, which are crucial indicators of lipid peroxidation (Gao et al., 2013; Wang et al., 2012; Liu et al., 2024). The reduction in MDA levels implies a protective impact against lipid oxidative damage, which strengthens the probiotic's involvement in antioxidant defense.

Table 1. Based on findings from various literature sources, the antioxidant activity of *L. Plantarum*.

PB strain name	Sources of PB	Dose/ concentration	Test medium/ cell line	Test type	Possible mechanism (s)	References
L. plantarum	-	3.9×10^{8} CFU/mL	DPPH assay	*In vitro*	↓DPPH•	Mousavi et al., 2013
L. plantarum	Fermented kiwifruit pulp	10^{6} CFU kg^{-1}	DPPH and ABTS radical scavenging assay	*In vitro*	↑TPC, TFC, protocatechuic acid, and chlorogenic acid; ↓DPPH• and ABTS•+	Zhou et al., 2020
L. plantarum	Tomato seed	2×10^{6} CFU/ mL	DPPH, ABTS radicals scavenging assay	*In vitro*	↓TAC, GA, AA, DPPH•, ABTS•+	Mechmeche et al., 2017
L. plantarum	Apples, pears, and carrots	-	DPPH, ABTS radicals scavenging activities		↑TPC, TFC, SOD; ↓DPPH•, ABTS•+	Yang et al., 2018b
L. plantarum 120	Fermented foods	10^{8} CFU/mL	DPPH, Superoxide anion, Hydroxyl radical scavenging activity	*In vitro*	↑GSH-Px, SOD, T-AOC, ATP; ↓pH, DPPH•, O_2•−, •OH	Liu et al., 2024
L. plantarum 200655	Cabbage kimchi	1×10^{7} CFU/mL	RAW 264.7 cells	*In vitro*	↓DPPH•, ABTS•+, NO, IL-1β, IL-6, lipid peroxidation	Yang et al., 2018a

Table 1. *Continued*

PB strain name	Sources of PB	Dose/ concentration	Test medium/ cell line	Test type	Possible mechanism (s)	References
L. plantarum ATCC14917	Apple juice	0.45 µM	LC-MS/MS, CAA	*In vitro*	↑CAA, TPC, TFC; ↓ABTS•+, DPPH•	Li et al., 2018
L. plantarum C88	Fermented foods	10^6 cells mL^{-1}	DPPH, ABTS, and superoxide anion radicals scavenging activities, ageing male kunming mice	*In vitro* and *in vivo*	↑SOD, GSH-Px, CAT, T-AOC; ↓MDA	He et al., 2015
L. plantarum C88, (EPS)	-	0.5–4 mg/mL	Caco-2	*In vitro*	↑T-AOC, SOD; ↓MDA	Zhang et al., 2013
L. plantarum CD101	Chinese fermented sausages	10^7 CFU/g	Fermented supernatant, intact cell, and cell-free extract of L. plantarum	*In vitro*	↑SOD, peptide extraction; ↓DPPH•, Fe^{2+}, pH, protein band	Luan et al., 2021
L. plantarum CNPC003	Milk and dairy products	8 mg/mL	DPPH, ABTS, FRAP assay	*In vitro*	↑FRAP; ↓ABTS•+, DPPH•	Bomfim et al., 2020
L. plantarum DM5	Marcha	10^{10} CFU/mL	Hydroxyl radical, SOD, DPPH assay	*In vitro*	↑SOD; ↓DPPH•, •OH	Das & Goyal, 2015
L. plantarum FC225	Fermented cabbages	-	High-fat diet-fed mice	*In vivo*	↑GSH-Px, SOD ↓MDA	Gao et al., 2013
L. plantarum JLAU103	Hurood	10 mg/mL	DPPH, ABTS, Hydroxyl radical, Metal chelating activity test, ORAC assay	*In vitro*	↑GSH, ORAC; ↓•OH, ABTS•+, DPPH•	Min et al., 2019
L. plantarum JM113	Intestines of a healthy Tibetan chicken	1 × 10^9 CFU/kg	NADH, DPPH, PMS, NBT, 1-d-old arbor acres chicks	*In vitro*, and *in vivo*	↑SOD, GSH-Px; ↓MDA, H_2O_2, DPPH•, •OH	Yang et al., 2017
L. plantarum LAB 1	Fermented olive,	10^7–10^9 CFU/ mL	Linolenic acid test, β-carotene bleaching test	*In vitro*	↑TAA, AAC, ortho-diphenols; ↓DPPH•, cell concentrations	Kachouri et al., 2015
L. plantarum MA2	Tibetan kefir grains	1.0×10^{10} CFU/ mL	DPPH, Hydroxyl, SOD, GSH-Px, Fe^{2+}-chelating, lipid peroxidation assay,	*In vitro*	↑GSH-Px, SOD, Cat, GSH; ↓Npx, Fe^{2+}, MDA, DPPH•, •OH	Tang et al., 2017
L. plantarum MA2	Tibetan kefir grains	-	Caco-2 cells	*In vitro*	↑CAA	Tang et al., 2018
L. plantarum NJAU-01	Jinhua ham (Dry-cured meat)	1 mg/mL (p.o)	Kun Ming mice, D-galactose-induced subacute senescence of mice	*In vivo*	↑T-AOC, SOD, GSH-Px, CAT; ↓MDA	Ge et al., 2021
L. plantarum RG14, RG11 and TL1	-	10^9 CFU/mL	DPPH and ABTS radical scavenging assay	*In vitro*	↑GPX, Cu/Zn SOD, GPX1, GPX4; ↓MDA	Izuddin et al., 2020
L. plantarum ZLP001	Gastrointestinal tract (weaning piglet)	6.8´10^7 CFU/g	Hydrogen peroxide and free radical-scavenging activity, Piglets (n=96)	*In vitro* and *in vivo*	↑SOD, GSH-Px, CAT; ↓MDA	Wang et al., 2012
L. plantarum C88 and C10	Chinese fermented dairy tofu	4.0×10^{10} and 4.0×10^8 CFU/d (p.o)	Male Kunming mice, D-galactose-induced oxidative stressed	*In vivo* and *in vitro*	↑GSH-Px, T-AOC, SOD; ↓MDA, •OH, DPPH•	Li et al., 2012

Abbreviations: ↑: Increase/stimulation/up-regulation; ↓: decrease/inhibition/down-regulation; PB: Probiotic bacteria; DPPH: 2,2-diphenyl-1-picrylhydrazyl; ABTS: 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); T-AOC: Total antioxidant capacity; SOD: Superoxide dismutase; MDA: Malondialdehyde; CAT: Catalase; EPS: Exopolysaccharide; NO: Nitric oxide; IL: Interleukin; TAA: Total antioxidative activity; AAC: Antioxidant activity coefficient; ORAC: Oxygen radical absorbance capacity; TPC: Total phenolic content; TFC: Total flavonoid content; CAA: Cellular antioxidant activity; LC-MS/MS: Liquid chromatography-tandem mass spectrometry; Fe^{2+}: Ferrous (II) ion; pH: potential of hydrogen; GSH-Px: Glutathione peroxidase; NADH: Nicotinamide adenine dinucleotide; PMS: Phenazine methosulfate; NBT: Nitroblue tetrazolium; FRAP: Ferric reducing antioxidant power; cat: Catalase gene; npx: NADH peroxidase gene; gshr: Glutathione reductase genes; GPX: Glutathione peroxidase; GPX1: Glutathione peroxidase 1; GPX4: Glutathione peroxidase 4; Cu/Zn SOD: Cu, Zn Superoxide dismutase; •OH: Hydroxyl radical; TAC: Total amino acids; GA: Glutamic acid; AA: Aspartic acid; DPPH•: DPPH radical; ABTS•+: ABTS free radical; O_2•− :Superoxide radical; CFU: Colony-forming unit; p.o.: Oral gavage.

3.1.4. Polyphenol and flavonoid content

Several investigations emphasized the relationship between polyphenol content and antioxidant activity in *L. plantarum* strains. *L. plantarum* extracted from fermented kiwifruit and apple juice showed elevated total phenolic content (TPC) and total flavonoid content (TFC), which contributed to their significant antioxidant potential (Zhou et al., 2020; Li et al., 2018). This shows that the phenolic metabolites generated by *L. plantarum* improve free radical scavenging activities.

3.1.5. *In vivo* antioxidant effects

Beyond the *in vitro* tests, *in vivo* investigations also validated *L. plantarum*'s antioxidant properties. The C88 strain, widely recognized for its robust acid and bile salt tolerance, has shown substantial antioxidant capabilities. FC225, isolated from traditional fermented foods, exhibits strong probiotic properties along with antioxidant potential. The NJAU-01 strain, originally derived from dairy sources, has demonstrated superior radical scavenging activity. C88, FC225, and NJAU-01 strains dramatically increased antioxidant enzyme activity and lowered oxidative stress indicators in animal models (Li et al., 2012; Ge et al., 2021; Gao et al., 2013). The protective effects observed in animal studies further validate the potential application of *L. plantarum* in mitigating oxidative stress-related disorders. The possible antioxidant activity of *L. Plantarum* is represented in **Fig. 1.**

Our findings align with some previous studies on *L. plantarum*, which have reported similar antioxidant properties in different strains. A comparison with studies by He et al. (2015) and Zhang et al. (2013) reveals variations in antioxidant efficacy, likely due to strain-specific differences and environmental factors. For instance, strain NJAU-01 exhibited higher DPPH radical scavenging activity compared to strain C88 (He et al., 2015; Zhang et al., 2013). Despite extensive research on *L. plantarum*, previous studies have certain limitations. Many studies have focused on *in vitro* assays without sufficient validation in animal or human models. Additionally, some reports lack detailed strain characterization, making it challenging to compare findings across different research groups. Future studies should aim for more standardized methodologies and comprehensive *in vivo* analyses.

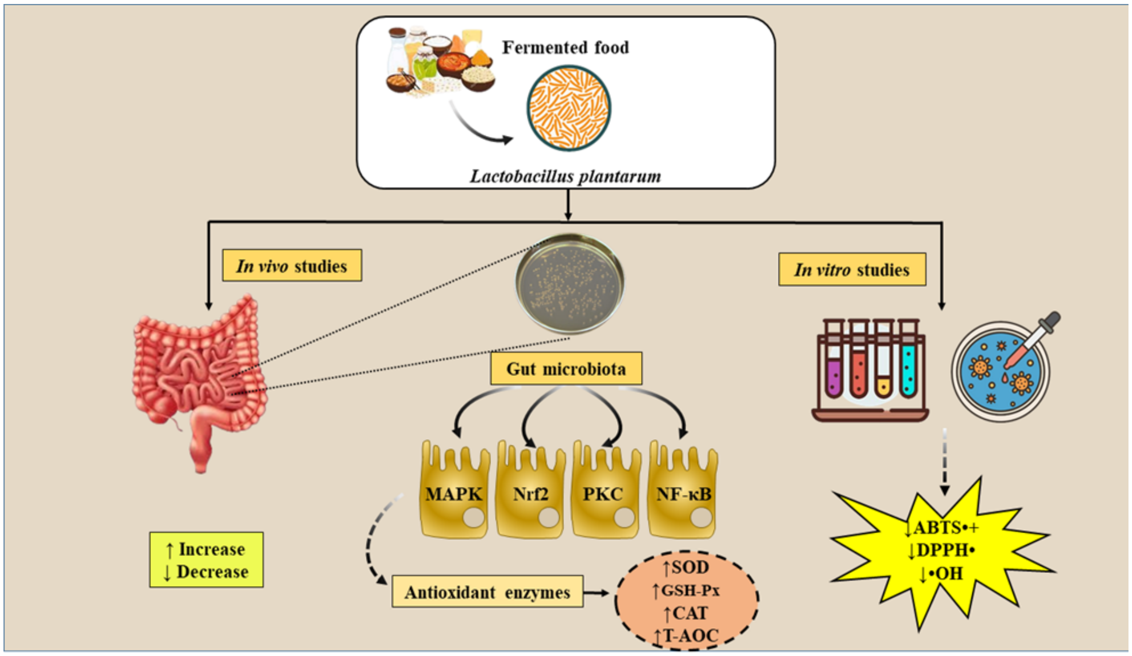

Fig. 1. Possible antioxidant activity of *Lactobacillus plantarum*. [SOD: Superoxide dismutase; GSH-Px: Glutathione peroxidase; CAT: Catalase; T-AOC: Total antioxidant capacity; •OH: Hydroxyl radical; DPPH•: DPPH radical; EPS: Exopolysaccharide; ABTS•+: ABTS free radical; MAPK: Mitogen-activated protein kinase; PKC: Protein kinase C; Nrf2: Nuclear factor erythroid 2-related factor 2; NF-κB: Nuclear factor-kappa B].

4. Conclusion and future perspectives

L. plantarum has strong antioxidant properties that help lower oxidative stress and associated illnesses. It enhanced free radical neutralization. Its capacity to scavenge free radicals, better cellular defense systems are noteworthy examples of the synergistic effects seen and boost enzymatic antioxidant activity by improving gut microbiota, exhibiting its therapeutic potential by preventing chronic diseases. However, further in-depth studies are required to explore its molecular mechanisms, optimize its application in functional foods, and assess its long-term safety. Future research should also focus on genetic modifications and novel delivery systems to enhance its stability and efficacy. Expanding clinical trials will be crucial to validating its benefits and facilitating its integration into mainstream healthcare and dietary interventions. *L. plantarum*'s advanced biotechnological uses might pave the path for its inclusion in preventative healthcare programs and the development of novel antioxidant medications.

Conflict of interest

The authors declared no conflict.

Data availability

Data will be made available on request.

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Author’s contributions

All authors made a major contribution to the work described, whether it was in the conception, research design, implementation, data gathering, analysis, and comprehension, or all of these areas, that is, modifying or critically assessing the paper; granting final consent to the version to be published; agreement on the journal to which the work has been submitted; and verifying accountability for all areas of the task. All authors have read and approved the published version of the text.

Abbreviations

•OH	: Hydroxyl radical
AA	: Aspartic acid
AAC	: Antioxidant activity coefficient
ABTS	: 2, 2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid)
ABTS•+	: ABTS free radical
CAA	: Cellular antioxidant activity
CAT	: Catalase
CAT	: Catalase gene
CFU	: Colony-forming unit
Cu/Zn SOD	: Cu, Zn Superoxide dismutase
DPPH	: 2, 2-diphenyl-1-picrylhydrazyl
DPPH•	: DPPH radical
EPS	: Exopolysaccharide
Fe^{2+}	: Ferrous (II) ion
FRAP	: Ferric reducing antioxidant power
GA	: Glutamic acid
GPX	: Glutathione peroxidase
GPX1	: Glutathione peroxidase 1
GPX4	: Glutathione peroxidase 4
GSH-Px	: Glutathione peroxidase
gshr	: Glutathione reductase genes
IL	: Interleukin
LAB	: Lactic acid bacterium
LC-MS/MS	: Liquid chromatography-tandem mass spectrometry
MDA	: Malondialdehyde
NADH	: Nicotinamide adenine dinucleotide
NBT	: Nitroblue tetrazolium
NO	: Nitric oxide
npx	: NADH peroxidase gene
O_2•−	: Superoxide radical
ORAC	: Oxygen radical absorbance capacity
PB	: Probiotic bacteria
pH	: Potential of hydrogen
PMS	: Phenazine methosulfate
ROS	: Reactive oxygen species
SOD	: Superoxide dismutase
TAA	: Total antioxidative activity
TAC	: Total amino acids
T-AOC	: Total antioxidant capacity
TFC	: Total flavonoid content
TPC	: Total phenolic content

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