The Protective Role of Probiotic-Rich Dairy by-Products in Mitigating Bisphenol a Toxicity: Antioxidant and Anti-Inflammatory Mechanisms

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Abstract

Bisphenol A (BPA) is a widely used industrial chemical, primarily employed in the production of synthetic polymers and thermal paper. Epidemiological surveys have indicated that BPA exposure can lead to toxic, endocrine-disrupting, mutagenic, and carcinogenic effects. This study explores the potential of probiotics, specifically *Lactobacillus rhamnosus* and *Lactobacillus plantarum*, in mitigating the harmful effects of BPA. The study consolidates findings from the past decade, focusing on preclinical in vitro studies and mouse models exposed to BPA. The findings suggest that probiotics can alleviate BPA-induced damage by decreasing its accumulation, reducing oxidative stress, and modulating inflammatory pathways. Furthermore, probiotics can improve gut microbiota diversity, which acts as a natural barrier to prevent the absorption of BPA. The paper highlights the potential of fermented dairy products to provide a dietary source of these beneficial bacteria. Given the rising concerns about BPA exposure, incorporating probiotics into the diet, especially through fermented dairy products, could be an effective preventive strategy. This review provides a comprehensive synthesis of existing literature and suggests future avenues for research in this field.

Keywords: *Bisphenol A, probiotics, fermented foods, Lactobacillus, oxidative stress, gut microbiota, endocrine disruptors, dairy by-products*

Introduction

Bisphenol A (BPA) is a chemical compound commonly used in the manufacturing of plastics and resins, including polycarbonate plastics and epoxy resins. BPA has raised widespread concern due to its endocrine-disrupting properties, which can interfere with hormone signaling and have been linked to various health issues such as infertility, cancer, and developmental abnormalities (Vandenberg et al., 2012). BPA is also a known xenoestrogen, mimicking the action of estrogen in the body, which is one of the main reasons for its biological impact.The human body absorbs BPA primarily through the consumption of contaminated food and drink, particularly from food stored in plastic containers or food packaging. The resulting exposure has prompted scientists to explore preventive and therapeutic strategies. In this context, probiotics, particularly *Lactobacillus rhamnosus* and *Lactobacillus plantarum*, have shown promise in mitigating BPA-induced effects due to their antioxidant and anti-inflammatory properties. These bacteria, commonly found in fermented dairy products, may play an essential role in protecting the gut and systemic health from BPA-induced oxidative stress and inflammatory damage.

Dairy By-products and Probiotics:

Dairy by-products, particularly fermented dairy products such as yogurt, kefir, and cheeses, have long been recognized for their health benefits, including improving gut health, modulating the immune system, and enhancing metabolic functions. These products are rich in beneficial microbes, particularly lactic acid bacteria (LAB) such as *Lactobacillus rhamnosus* and *Lactobacillus plantarum*, which have demonstrated therapeutic potential in various health conditions (Ouwehand et al., 2017).Fermented dairy products can help restore microbial balance in the gut, promote the growth of beneficial bacteria, and prevent the absorption of harmful compounds like BPA. *Lactobacillus* strains are also known for their ability to produce bioactive compounds, such as lactic acid, that exhibit antimicrobial and antioxidant properties (Parvez et al., 2015). These bacteria can play a crucial role in counteracting the oxidative stress induced by BPA, thereby providing a protective mechanism.

Mechanisms of Action:

BPA Binding and Absorption Prevention:

Recent research has shown that *Lactobacillus rhamnosus* and *Lactobacillus plantarum* possess the ability to bind BPA through structures such as lipopolysaccharides and teichoic acids on their cell walls. By binding BPA, these probiotics prevent its absorption through the intestinal wall, limiting its entry into the bloodstream and reducing its endocrine-disrupting effects (Mennigen et al., 2009). This barrier function could significantly reduce BPA's toxic impact, especially in individuals exposed to high levels of this compound.

Biotransformation of BPA:

Another key mechanism through which probiotics exert their protective effect is through the biotransformation of BPA. Both *Lactobacillus rhamnosus* and *Lactobacillus plantarum* are capable of producing enzymes that degrade BPA into less toxic metabolites. These enzymes, such as glucuronidases and sulfatases, convert BPA into water-soluble metabolites, making it easier for the body to eliminate BPA through urine or feces (Chauhan et al., 2020). This biotransformation process is critical in reducing BPA's long-term accumulation in tissues and its potential harmful effects.

Anti-inflammatory and Antioxidant Properties:

In addition to preventing BPA absorption and enhancing its elimination, probiotics can mitigate BPA's oxidative stress and inflammation. BPA is known to induce oxidative damage by increasing the production of reactive oxygen species (ROS), which can damage cellular structures, including lipids, proteins, and DNA. Probiotics like *Lactobacillus rhamnosus* and *Lactobacillus plantarum* exhibit antioxidant activities that scavenge ROS and reduce cellular damage (Lee et al., 2018). Additionally, these probiotics can modulate inflammatory pathways, reducing the production of pro-inflammatory cytokines such as TNF-α and IL-6, which are elevated in BPA-exposed individuals (Liu et al., 2017).

Methodology

A structured literature review was conducted using prominent databases, including MEDLINE, Embase, Current Contents, and the Cochrane Library. The aim was to gather comprehensive data regarding the pharmacological effects, detoxification mechanisms, and dietary applications of probiotics in mitigating BPA toxicity.

Search Strategy

The literature search included the following keywords: *Bisphenol A*, *probiotics*, *fermented dairy products*, *Lactobacillus rhamnosus*, *Lactobacillus plantarum*, *oxidative stress*, and *inflammation*. Articles published in English were included, ensuring a diverse representation of scientific findings.

Inclusion Criteria

- Studies including randomized controlled trials (RCTs), cohort studies, case-control studies, observational studies, meta-analyses, or systematic reviews.
- Research articles investigating the biochemical and pharmacological roles of probiotics in BPA detoxification.
- Studies assessing probiotic-rich dairy products as potential dietary interventions.
- Experimental studies evaluating oxidative stress and inflammatory markers in BPA-exposed models treated with probiotics.

Data Extraction and Analysis

The selected studies were analyzed based on their relevance and contribution to understanding the role of probiotics in mitigating BPA toxicity. The extracted data were categorized into key aspects: probiotic binding mechanisms, biotransformation of BPA, antioxidant effects, and anti-inflammatory responses.

Results and Discussion

Probiotic Mechanisms in BPA Detoxification

Mechanism	Description	Key Findings
BPA Binding	Probiotics bind BPA in the gut, preventing absorption.	*Lactobacillus* strains have cell wall components that interact with BPA, reducing systemic uptake.
Biotransformation	Probiotic enzymes convert BPA into less toxic metabolites.	BPA is metabolized into water-soluble derivatives, facilitating excretion.
Antioxidant Activity	Probiotics reduce oxidative stress caused by BPA exposure.	Increased glutathione levels and decreased malondialdehyde (MDA) observed in probiotic-treated groups.
Anti-inflammatory Effects	Probiotics modulate inflammatory cytokines induced by BPA.	Significant reduction in TNF-α and IL-6 levels in experimental studies.

Experimental Studies

Study Design

To further explore the protective role of probiotics against BPA exposure, a recent study employed a rodent model where male mice were exposed to BPA at a dose of 50 mg/kg/day for six weeks. The mice were divided into six groups: (1) control, (2) BPA, (3) BPA + *Lactobacillus plantarum* (LY-08), (4) BPA + probiotic mixture (LY-02 and LY-08), (5) probiotic mixture alone, and (6) BPA + corn oil. The study aimed to examine the effects of *Lactobacillus* strains on the accumulation of BPA and the associated physiological and biochemical markers of oxidative stress and inflammation.

Findings

The results demonstrated that the probiotic mixture (LY-02 and LY-08) significantly reduced BPA accumulation in tissues, particularly in the serum, gut, and testicular tissues. The treatment also improved gut integrity, as evidenced by increased tight junction protein levels and reduced permeability. In terms of oxidative stress, the probiotic-treated groups showed lower levels of malondialdehyde (MDA) and higher levels of reduced glutathione (GSH), indicating a reduction in lipid peroxidation and enhanced antioxidant capacity. Furthermore, the probiotic mixture reduced inflammation markers, including TNF-α and NF-κB, highlighting its anti-inflammatory effects (Wang et al., 2022).

These findings support the hypothesis that probiotics, particularly *Lactobacillus rhamnosus* and *Lactobacillus plantarum*, can counteract the adverse effects of BPA through a combination of binding, biotransformation, and modulation of oxidative stress and inflammation

Preclinical animal studies demonstrated that probiotic intervention significantly reduced BPA accumulation in tissues, improved gut integrity, and modulated oxidative stress markers.

Table 2 presents key experimental outcomes.

Study Model	Probiotic Strain	BPA Dose	Effects
Mouse	*Lactobacillus plantarum*	50 mg/kg/day	Decreased BPA serum levels, improved gut barrier function
Mouse	Probiotic mixture (*L. rhamnosus* + *L. plantarum*)	50 mg/kg/day	Reduced oxidative stress (lower MDA, higher GSH)
Rat	*Lactobacillus rhamnosus*	25 mg/kg/day	Lowered inflammatory cytokines, enhanced BPA metabolism

Future Research Directions:

Despite the promising results from animal models, further studies are needed to translate these findings to human populations. Future research should focus on:

1. **Human Clinical Trials:** Conducting randomized controlled trials to confirm the efficacy of probiotics in mitigating BPA-induced toxicity in humans.
2. **Mechanistic Studies:** Investigating the exact molecular mechanisms by which probiotics prevent BPA absorption and modulate oxidative stress.
3. **Long-Term Effects:** Assessing the long-term effects of probiotic intervention in individuals with chronic BPA exposure, particularly in vulnerable populations such as pregnant women and children.
4. **Probiotic Formulations:** Developing and testing probiotic formulations specifically designed to mitigate BPA toxicity through controlled dosing and targeted delivery.

Conclusion

The findings suggest that probiotic-rich dairy products, particularly those containing *Lactobacillus rhamnosus* and *Lactobacillus plantarum*, offer a promising natural intervention against BPA toxicity. Through binding, biotransformation, and modulation of oxidative and inflammatory responses, probiotics can mitigate the harmful effects of BPA.

Moreover, incorporating probiotics into daily dietary habits can provide a practical and sustainable approach to counteracting BPA exposure. As research progresses, the development of specialized probiotic formulations and functional dairy products could further enhance BPA detoxification strategies. Additionally, interdisciplinary studies integrating microbiology, nutrition, and toxicology will be essential to fully elucidate the long-term benefits of probiotic-based interventions. Public awareness and regulatory measures should also support the widespread use of probiotics as a preventive strategy against BPA-related health risks.

Future research should focus on translating these findings into clinical applications and optimizing probiotic strains that exhibit the highest efficacy in detoxifying BPA. Large-scale human studies will be necessary to confirm these benefits and establish standardized guidelines for probiotic consumption as a protective measure against environmental toxins.

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