

EFFECT OF PH, TEMPERATURE, AND VISCOSITY ON BISPHENOL A MIGRATION FROM BPA-PRE-COATED POLYPROPYLENE (PP) CONTAINERS INTO CHICKEN FEET BROTH ANALYZED BY GC-MS

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Abstract

The background of this work is based on the fact that Bisphenol A (BPA) is a synthetic chemical widely used in plastic-related industries and is known for its potential to migrate into food, raising concerns regarding food safety and public health, particularly for liquid and protein-rich foods such as broths packaged in plastic containers. The objective is to evaluate the effects of pH, temperature, and viscosity on BPA migration from BPA-pre-coated polypropylene (PP) containers into chicken feet broth. BPA migration experimental methods were performed under controlled variations of pH (3-6), temperature (10-80 °C), and viscosity levels using chicken feet broth as a real liquid food matrix, with BPA concentrations quantified by Gas Chromatography-Mass Spectrometry (GC-MS) and statistically analysed using one-way Analysis of Variance (ANOVA). The results show that BPA was detected in all samples, with broth viscosity exerting the strongest influence on BPA migration, where lower-viscosity broth exhibited higher BPA concentrations, while variations in temperature and pH did not produce statistically significant effects under the tested conditions.

Keywords: Bisphenol A (BPA), Food safety, Mass spectrometry, Polypropylene packaging, Viscosity effects.

1. Introduction

Plastic packaging is extensively utilized in the food industry due to its low cost, lightweight properties, mechanical durability, and ease of processing. Despite these advantages, plastic materials are not chemically inert and may release low-molecular-weight compounds into food products during contact, a phenomenon known as chemical migration [1, 2]. Among these compounds, Bisphenol A (BPA) has received considerable scientific and regulatory attention due to its widespread use and potential health risks.

BPA is a synthetic organic compound commonly employed in the manufacture of polycarbonate plastics and epoxy resins. Numerous studies have demonstrated that BPA can migrate into food and beverages, particularly under conditions involving heat, prolonged contact time, or specific food compositions [3-5]. BPA is classified as an endocrine-disrupting compound capable of mimicking estrogenic activity, and chronic exposure has been linked to reproductive disorders, metabolic dysfunction, immune modulation, and developmental toxicity [6, 7].

Polypropylene (PP) is widely regarded as a safer alternative to polycarbonate because BPA is not intentionally used as a monomer in its polymerization process. Consequently, PP is extensively applied in food containers, ready-to-eat packaging, and liquid food storage [8]. However, several investigations have reported detectable BPA levels in foods packaged in PP materials, suggesting possible sources such as cross-contamination during manufacturing, additive degradation, or indirect migration from recycled or multilayer packaging systems [9-11]. These findings indicate that PP packaging cannot be assumed to be entirely free from BPA contamination.

Chemical migration from packaging to food is governed by a combination of material properties, environmental conditions, and food matrix characteristics. Temperature and pH have been extensively studied as key external drivers influencing diffusion kinetics and polymer stability [12, 13]. Elevated temperatures generally enhance molecular mobility within polymer matrices, accelerating migration rates, while acidic conditions may promote polymer degradation and additive release [14]. Nevertheless, emerging studies emphasize that intrinsic food properties, particularly viscosity and matrix composition, play a crucial role by controlling mass-transfer resistance and solute diffusion behaviour [15, 16].

Liquid foods represent a critical exposure pathway for BPA due to their large contact surface area with packaging materials and their capacity to solubilize organic contaminants. Protein- and collagen-rich broths, such as chicken feet broth, constitute complex food matrices containing lipids, amino acids, and gelatinized proteins that may interact with BPA differently compared to aqueous or fatty food simulants typically employed in migration studies [17, 18]. Despite their widespread consumption, particularly in Asian diets, scientific evidence regarding BPA migration into collagen-rich liquid foods remains limited, representing a clear research gap.

Most existing studies on bisphenol A (BPA) migration from food packaging primarily emphasize the effects of temperature, storage duration, or packaging type, while the role of intrinsic food properties - particularly viscosity - remains insufficiently explored. This limitation is further amplified by the widespread reliance on food simulants rather than real food matrices, which may not accurately represent complex physicochemical interactions occurring in actual foods. Consequently, important knowledge gaps persist regarding BPA behaviour in collagen-rich liquid

foods. In response to this gap, the present study addresses three key research questions: whether BPA is detectable in chicken feet broth packaged in polypropylene containers, how variations in pH, temperature, and viscosity influence BPA migration, and which physicochemical factor most strongly governs BPA migration in a liquid food system.

The objective of this study is to quantitatively evaluate BPA migration from effects of pH, temperature, and viscosity on BPA migration into chicken feet broth from BPA-pre-coated polypropylene (PP) containers using Gas Chromatography-Mass Spectrometry (GC-MS) under controlled variations of pH, temperature, and viscosity. This paper advances the thesis that food viscosity exerts a more dominant influence on BPA migration than temperature and pH by modulating molecular mobility and diffusion resistance within the food matrix. The scope of the study is limited to laboratory-controlled conditions and does not consider long-term storage effects, repeated container use, or interactions with multiple food additives. The novelty of this research lies in its integrated assessment of viscosity, pH, and temperature effects on BPA migration in a collagen-rich liquid food matrix, thereby offering a more realistic and application-oriented framework for evaluating chemical migration risks associated with polypropylene food packaging.

2. Literature Study

2.1. Mapping of key theories and concepts

Chemical migration from food contact materials is a diffusion-driven process governed by polymer structure, additive properties, environmental conditions, and food matrix characteristics. According to migration theory, low-molecular-weight compounds such as Bisphenol A (BPA) can diffuse from polymer matrices into contacting food when thermodynamic equilibrium and kinetic conditions permit [1, 2]. BPA is widely recognized as an endocrine-disrupting compound with estrogenic activity, capable of interfering with hormonal regulation even at low exposure levels [6, 7]. A graphical description of BPA is found in Fig. 1.

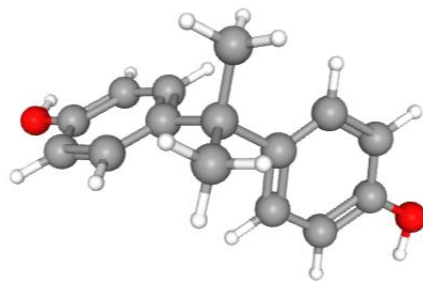


Fig. 1. Three-dimensional ball-and-stick molecular structure of bisphenol.

A (BPA), showing two phenyl rings connected by an isopropylidene bridge with terminal hydroxyl (-OH) groups. Carbon atoms are shown in grey, oxygen atoms in red, and hydrogen atoms in white. The molecular structure was obtained from the PubChem database.

From a materials science perspective, polypropylene (PP) is categorized as a non-BPA polymer; however, contamination pathways such as additive degradation, recycled polymer use, and cross-contamination during manufacturing may introduce

BPA into PP-based food packaging [9, 10]. Migration behaviour is further influenced by external factors such as temperature and pH, which affect polymer chain mobility, solubility of migrants, and chemical stability [12-14].

Equally important are intrinsic food properties, including viscosity, composition, and macromolecular structure. Diffusion theory suggests that higher viscosity increases mass-transfer resistance, potentially limiting contaminant migration, while lower viscosity facilitates molecular mobility and solute transport [15, 16]. These concepts form the theoretical foundation for understanding BPA migration in real liquid food systems.

2.2. Synthesis and comparison of previous studies

Previous studies have extensively documented BPA migration from polycarbonate and epoxy resin-based materials into food and beverages, particularly under elevated temperatures and prolonged contact times [3-5]. Research focusing on PP packaging generally reports lower BPA levels compared to polycarbonate; however, detectable concentrations have still been observed in various food products, challenging the assumption that PP is entirely BPA-free [9-11].

Temperature has consistently been identified as a dominant factor influencing BPA migration, with higher temperatures accelerating diffusion and polymer relaxation [14, 19]. pH effects have also been reported, particularly under acidic conditions that may promote polymer degradation or chemical instability of additives [20]. Nevertheless, most studies rely on standardized food simulants rather than real food matrices, limiting their applicability to actual consumption scenarios [21].

More recent investigations highlight the importance of food matrix effects, including fat content, protein interactions, and rheological properties, in governing chemical migration [17, 18]. However, systematic evaluation of viscosity as an independent variable - especially in collagen-rich liquid foods such as broths - remains scarce in the literature.

2.3. Identification of knowledge gaps

Despite extensive research on BPA migration, it remains clear that not all sources of BPA have been identified [22]. Furthermore, several critical gaps still persist. First, most migration studies prioritize external conditions such as temperature and storage duration while underrepresenting intrinsic food properties, particularly viscosity. Second, the majority of experimental designs employ food simulants rather than real, compositionally complex foods, which may lead to under- or overestimation of migration risks. Third, limited studies have simultaneously examined the combined effects of pH, temperature, and viscosity within a single experimental framework. These gaps underscore the need for migration studies using realistic liquid food matrices and integrated physicochemical analyses.

2.4. Theoretical framework

Based on migration and diffusion theory, this study adopts a framework in which bisphenol A (BPA) migration from polypropylene packaging into liquid food is governed by the interaction of three domains: packaging-related factors (polymer structure and contamination pathways), environmental conditions (temperature and pH), and food matrix properties (viscosity and composition). Packaging characteristics determine BPA availability at the polymer-food interface, while

temperature and pH influence molecular mobility and chemical stability. Food matrix viscosity plays a critical role by regulating diffusion kinetics and mass-transfer resistance within the liquid phase, thereby controlling BPA transport away from the packaging surface. Within this framework, viscosity is hypothesized to exert a more dominant influence on BPA migration than temperature and pH under controlled conditions. This integrated approach provides the theoretical basis for examining BPA behaviour in chicken feet broth as a realistic liquid food matrix.

3. Methods

Figure 2 illustrates the system architecture and experimental workflow employed to evaluate bisphenol A (BPA) migration from polypropylene food-contact packaging into a liquid food matrix. The diagram provides an integrated overview of the migration source, the controlled physicochemical conditions applied to the liquid food matrix (pH, temperature, and viscosity), the analytical pathway based on GC - MS, and the performance metrics used for quantitative evaluation. This schematic representation clarifies the interaction between packaging materials, environmental parameters, and food matrix properties in governing BPA mass transfer behaviour.

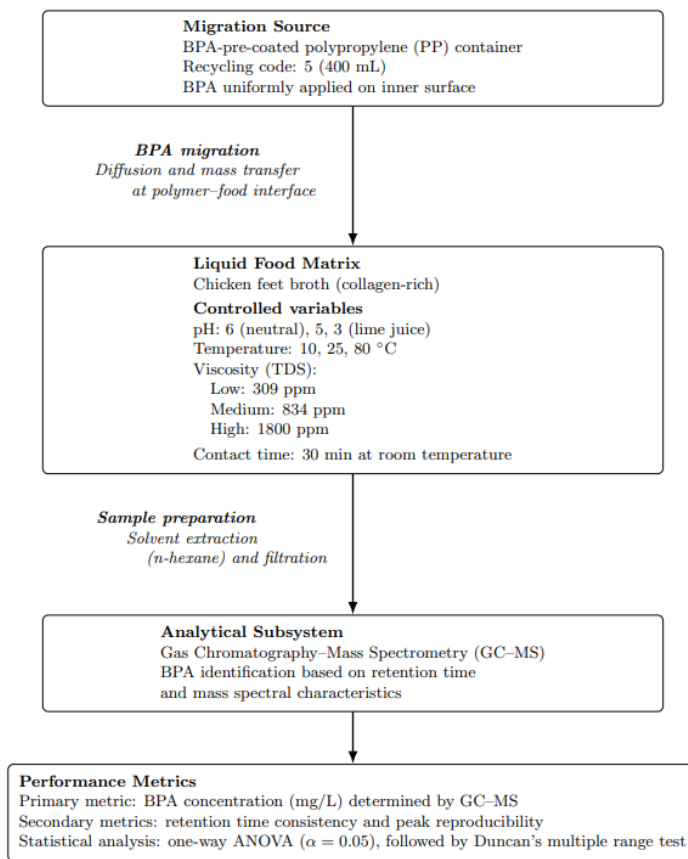


Fig. 2. Schematic representation of the experimental system for bisphenol A (BPA) migration analysis from BPA-pre-coated polypropylene (PP) containers into chicken feet broth.

Figure 2 illustrates the migration source, controlled liquid food matrix conditions (pH, temperature, and viscosity), GC-MS analytical workflow, and performance metrics used to evaluate BPA mass transfer behaviour.

3.1. System architecture

The experimental system was designed to simulate bisphenol A (BPA) migration from food-contact packaging into a real liquid food matrix under controlled physicochemical conditions. The system architecture consisted of three main subsystems: (1) a BPA-pre-coated polypropylene (PP) container acting as the migration source, (2) chicken feet broth as a collagen-rich liquid food matrix serving as the receiving medium, and (3) an analytical subsystem based on Gas Chromatography-Mass Spectrometry (GC-MS) for BPA detection and quantification. BPA was uniformly applied to the inner surface of PP containers to represent potential surface contamination, while migration was driven by controlled variations in pH, temperature, and viscosity. The overall system was structured to isolate each factor independently, allowing direct evaluation of its influence on BPA mass transfer from the polymer-food interface

3.2. Experimental setup

The experimental setup followed a laboratory-scale controlled design adapted from the undergraduate experimental framework of Syalsa Dania Putri and was refined to meet journal-level methodological requirements. A BPA stock solution (10 mg/mL) was prepared by dissolving analytical-grade BPA in n-hexane and subsequently diluted to obtain a working solution with a concentration of 1 mg/mL. One millilitre of the working solution was evenly distributed over the base and lower wall surfaces of each polypropylene (PP) container using a micropipette. The containers were then allowed to dry at room temperature for 30 minutes to ensure complete solvent evaporation and uniform BPA coating on the contact surface.

Chicken feet broth was prepared using a standardized formulation consisting of 500 g of chicken feet boiled in 2 L of distilled water to maintain consistent matrix composition across all experiments. Temperature treatments were applied at 10 °C, 25 °C, and 80 °C to represent cold, ambient, and high-temperature food-contact conditions, respectively. The pH of the broth was adjusted to pH 6 (neutral), pH 5, and pH 3 using lime juice, simulating common culinary practices and acidic food environments. Broth viscosity was modified by varying water volume and cooking duration, resulting in low (309 ppm), medium (834 ppm), and high (1800 ppm) viscosity levels, as quantified using a Total Dissolved Solids (TDS) meter. After preparation, the broth samples were poured into the BPA-coated PP containers and allowed to remain in contact for 30 minutes at room temperature prior to extraction and analysis. All experiments were conducted at the National Research and Innovation Agency (BRIN), Serpong, Indonesia, from June to July 2025.

3.3. Performance metrics

System performance was evaluated using quantitative and statistical metrics relevant to chemical migration analysis. The primary performance metric was BPA concentration (mg/L) detected in the broth samples using GC-MS, identified based on characteristic retention times and mass spectral patterns. Secondary metrics included consistency of retention time, reproducibility of peak intensity, and variation of BPA

concentration across experimental conditions. Statistical performance was assessed using one-way Analysis of Variance (ANOVA) at a significance level of $\alpha = 0.05$ to determine the effect of pH, temperature, and viscosity on BPA migration. These metrics collectively reflect the efficiency of mass transfer from the polymer surface to the liquid food matrix and the reliability of the analytical system.

4. Results

4.1. BPA analysis using gas chromatography - Mass spectrometry (GC-MS)

Polypropylene (PP) is a thermoplastic polymer widely used as a food packaging material, including disposable containers, beverage bottles, and ready-to-eat food packaging, due to its favourable mechanical strength, chemical resistance, and thermal stability. PP is generally considered safer than polycarbonate plastics because bisphenol A (BPA) is not intentionally used as a monomer in its polymerization process [22]. However, several studies have reported the presence of BPA in PP-based products, which may arise from cross-contamination during manufacturing, degradation of additives, recycled material usage, mixed plastic layers, or indirect migration from other packaging components [9]. These findings indicate that PP packaging cannot be assumed to be completely free from BPA contamination.

Gas Chromatography-Mass Spectrometry (GC-MS) is a highly effective analytical technique for BPA detection owing to its high sensitivity, selectivity, and capability to separate target analytes from complex food and polymer matrices. Prior to GC analysis, BPA is commonly extracted using non-polar organic solvents such as n-hexane to ensure efficient isolation from the sample matrix, while derivatization agents (e.g., BSTFA) may be employed in some protocols to enhance analyte volatility and analytical stability. In the present study, GC-MS analysis was applied to identify and quantify BPA migration into chicken feet broth packaged in PP containers under controlled variations of viscosity, temperature, and pH. Statistical evaluation of the experimental data was performed using one-way Analysis of Variance (ANOVA) for each treatment factor to determine potential differences among conditions, and the corresponding results are summarized in Tables 1-3.

4.2. Effect of broth viscosity on BPA concentration

Table 1 shows BPA concentration in chicken feet broth with different viscosity levels. ANOVA results showed that the highest BPA concentration was observed in low-viscosity broth (57.95 mg/L), while significantly lower concentrations were measured in medium- and high-viscosity broths (17.41 mg/L and 19.27 mg/L, respectively). Although statistical analysis indicated no significant difference at the 95% confidence level, a clear decreasing trend in BPA concentration was observed with increasing viscosity.

Table 1. BPA concentration in chicken feet broth with different viscosity levels

Treatment	BPA concentration (mg/L)
Low (control)	57.95 ± 21.53 ^a
Medium	17.41 ± 3.91 ^a
High	19.27 ± 2.84 ^a

Different superscript letters in the same column indicate significant differences at $\alpha = 0.05$.

4.3. Effect of temperature on BPA concentration

Table 2 presents the measured BPA concentrations in chicken feet broth under different temperature conditions. Statistical evaluation using one-way Analysis of Variance (ANOVA) yielded a significance value of 0.561 ($p > 0.05$), indicating that variations in temperature within the tested range did not produce statistically significant differences in BPA concentration. This result suggests that, under the experimental conditions employed, temperature alone was not a dominant factor governing BPA migration from the polypropylene (PP) container into the liquid food matrix.

Table 2. BPA concentration at different temperature conditions

Temperature	BPA concentration (mg/L)
10 °C	53.19 ± 25.11 ^a
25 °C	38.13 ± 5.28 ^a
80 °C	37.62 ± 2.47 ^a

Different superscript letters in the same column indicate significant differences at $\alpha = 0.05$.

4.4. Effect of pH on BPA concentration

Table 3 present BPA concentration at different pH conditions. ANOVA results showed that BPA concentration decreased with decreasing pH. The lowest BPA concentration was observed at pH 3 (30.41 mg/L), while higher values were detected at pH 5 and pH 6. Acidic conditions promote BPA degradation through hydrolysis or oxidation, reducing the amount of free BPA available for detection [7].

Table 3. BPA concentration at different pH conditions

pH	BPA concentration (mg/L)
6	57.95 ± 21.53 ^a
5	40.30 ± 0.26 ^a
3	30.41 ± 7.98 ^a

Different superscript letters in the same column indicate significant differences at $\alpha = 0.05$.

4.5. Overall migration behaviour

GC-MS analysis confirmed that BPA was detected in all samples, with consistent retention times between 12.25 and 12.28 minutes, matching the BPA standard. Final BPA concentrations ranged from 14.637 to 73.177 ppm depending on treatment conditions. These results demonstrate that BPA migration from PP packaging into chicken feet broth is influenced by multiple factors, with viscosity showing the most pronounced effect, followed by temperature and pH. Similar multi-factor influences on BPA migration have been reported in previous studies [11, 23, 24].

5. Discussion

From Fig. 3, it can be inferred that lower-viscosity media facilitate higher BPA migration due to enhanced molecular mobility and reduced diffusion resistance. In contrast, higher viscosity restricts molecular movement within the liquid matrix, thereby limiting BPA diffusion from the PP surface into the food. These findings indicate that viscosity exerts a stronger influence on BPA migration compared to temperature and pH. Similar observations have been reported, where dilute or aqueous food systems showed higher BPA solubilization than dense or viscous

matrices [18, 25]. Increased viscosity reduces mass transfer and diffusion rates, thereby lowering detectable BPA levels [15].

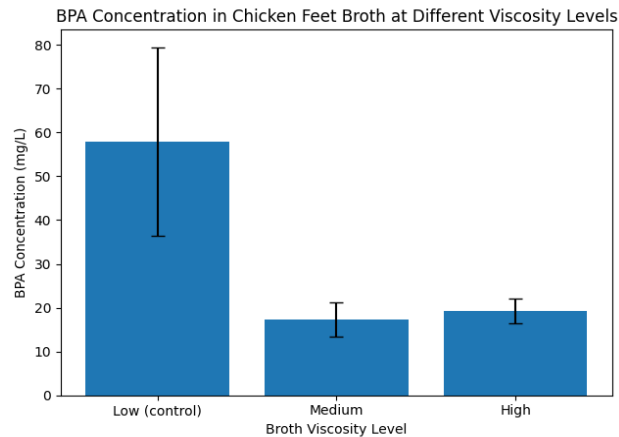


Fig. 3. Effect of broth viscosity on bisphenol A (BPA) concentration in chicken feet broth packaged in polypropylene containers. Bars represent mean BPA concentrations, and error bars indicate standard deviation. Statistical analysis showed no significant differences among viscosity treatments at $\alpha = 0.05$.

Based on Fig. 4, it can be seen that at elevated temperatures, BPA may interact more strongly with broth components such as proteins and lipids, reducing its solubility in hexane during extraction and leading to lower GC-MS detection [18]. PP packaging remains structurally stable at temperatures up to approximately 100-120 °C, so increased BPA release due to polymer degradation at 80 °C is unlikely [22]. Moreover, BPA has a melting point of approximately 158 °C and may partially volatilize or co-evaporate with water vapor at high temperatures, further reducing detectable concentrations [17].

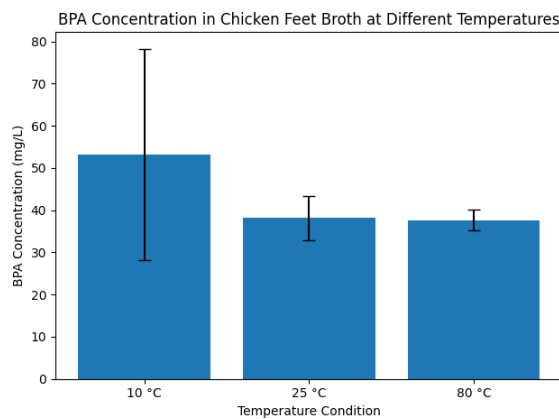


Fig. 4. Effect of temperature on bisphenol A (BPA) concentration in chicken feet broth packaged in polypropylene containers. Bars represent mean BPA concentrations, and error bars indicate standard deviation. No statistically significant differences were observed among temperature treatments at $\alpha = 0.05$.

Although elevated temperature is generally associated with increased BPA migration [19], the presents results suggest that in complex food matrices such as chicken feet broth, BPA stability and matrix interactions play a critical role. Lower temperatures may preserve BPA integrity, resulting in higher detectable levels during GC-MS analysis [12,16].

As depicted in Fig. 5, at near-neutral pH, BPA remains more chemically stable, facilitating its migration and detection [26]. Lime juice, used to acidify the broth, contains citric acid and exhibits pH values between 2 and 3. Previous studies have shown that acidic environments can suppress BPA release or accelerate its degradation, depending on matrix interactions [14, 24]. Although acidic conditions may act as extractive agents, excessive acidity can destabilize BPA molecules, resulting in lower measurable concentrations. The result highlights that pH also affects ionization behaviour and analyte stability during GC-MS analysis. Near-neutral pH conditions favour stable analyte detection, whereas extreme acidity can interfere with extraction efficiency and compound integrity [19]. Despite the absence of statistically significant differences, pH remains an important factor in optimizing BPA detection conditions.

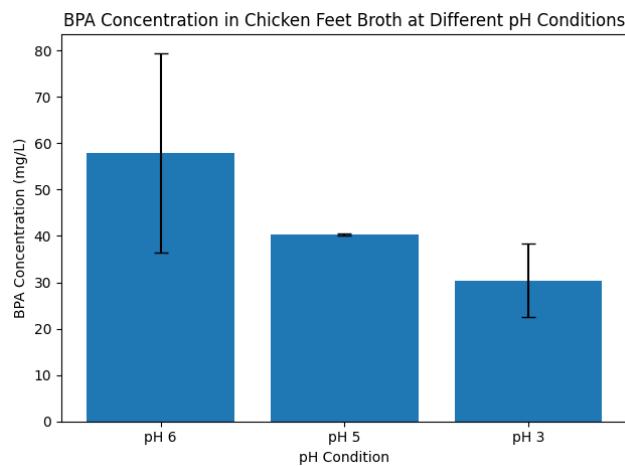


Fig. 5. Effect of pH on bisphenol A (BPA) concentration in chicken feet broth packaged in polypropylene containers.

Bars in Fig. 5 represent mean BPA concentrations, and error bars indicate standard deviation. No statistically significant differences were observed among pH treatments at $\alpha = 0.05$.

6. Conclusion

This study demonstrated that BPA migration into chicken feet broth from BPA-pre-coated polypropylene (PP) containers occurs under all tested conditions, confirming that BPA-pre-coated polypropylene (PP) containers cannot be considered entirely free from BPA contamination. Among the evaluated factors, broth viscosity showed the most pronounced influence on BPA migration, with low-viscosity broth exhibiting the highest BPA concentrations. In contrast, variations in temperature and pH did not produce statistically significant differences, although clear trends were

observed. Lower temperatures resulted in higher detectable BPA levels, likely due to greater compound stability, while acidic conditions tended to reduce BPA concentrations, possibly through chemical degradation or altered extraction efficiency. These findings provide a synthesized answer to the research questions by highlighting viscosity as the dominant physicochemical parameter governing BPA migration in complex liquid food systems.

From a practical perspective, the results suggest that dilute, water-based foods may present a higher risk of BPA exposure when packaged in polypropylene containers, underscoring the need for improved packaging assessment and food safety monitoring. These findings may inform food packaging policies, particularly for ready-to-eat liquid foods, by encouraging stricter evaluation of chemical migration even in materials considered relatively safe. Future research is recommended to investigate long-term storage effects, repeated container use, and the combined influence of multiple food additives and real consumer handling conditions. Additionally, expanding the study to other food matrices and applying advanced analytical or computational modelling approaches could further enhance understanding of BPA migration mechanisms and support evidence-based risk assessment.

Author Contribution

FH contributed to the conceptualization of the study, overall supervision, acquisition, manuscript writing, and graph visualization. SDP was responsible for experimental work, data collection, and data analysis. SRRP contributed to supervision and data interpretation. TS provided the data analysis and interpretation, paper drafting, and visualization CK provided supervision and contributed to data analysis. All authors reviewed and approved the final manuscript.

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Informed Consent Statement

Not applicable. This study did not involve human participants.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request. All experimental data were generated through laboratory experiments conducted by the authors and are not derived from artificial intelligence-generated sources. During the preparation of this manuscript, the authors used ChatGPT (OpenAI) solely for language refinement and rephrasing of the text. No AI tools were used for data generation, data analysis, or interpretation of experimental results.

Conflicts of Interest

The authors declare no conflicts of interest. The funders had no role in the study design; in the collection, analysis, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Nomenclatures

<i>BPA</i>	Bisphenol A
<i>PP</i>	Polypropylene
<i>GC-MS</i>	Gas Chromatography-Mass Spectrometry

Abbreviations

ANOVA	Analysis of Variance
BPA-PC	BPA-pre-coated polypropylene container
BRIN	National Research and Innovation Agency of Indonesia
CRD	Completely Randomized Design
SPSS	Statistical Package for the Social Sciences
TDS	Total Dissolved Solids

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