A Study Based on BIS Standard IS9845:1998 for Assessing the Migration of Bisphenol A from Food Contact Plastics

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Abstract

Plastics are extensively utilized in the food packaging industry, where they come into direct contact with food products. During processing or storage, the influence of physical factors may cause these plastics to release chemicals into food. This study applied the testing conditions outlined in the Bureau of Indian Standards (BIS) method IS9845:1998 to evaluate the migration of bisphenol A (BPA), an endocrine-disrupting chemical, from plastic containers intended for food contact. We selected three types of polymers for analysis: polycarbonate (PC), polyethylene terephthalate (PET), and polypropylene (PP). The investigation involved the use of five different food simulants under a variety of temperature and storage duration conditions. The BPA that migrated into the simulants was extracted via solid phase extraction (SPE) and analysed using a reverse-phase high-performance liquid chromatography (HPLC) system. Data analysis and interpretation were performed using the SPSS and R software packages. The results suggest that aqueous food substances, regardless of their acidity, are more susceptible to BPA contamination when in contact with PC containers subjected to elevated temperatures and/or extended storage periods.

Background

The United States, China, Brazil, and India are the countries with the fastest-growing plastic markets. In India, the per capita consumption of plastics is approximately 13.6 kg, 59% of which are used solely for packaging purposes (FICCI, 2020). Polyethylene, polypropylene, polystyrene, and polycarbonate are various types of plastics used in food packaging. Among these materials, polycarbonate (PC) is an engineering plastic known for its ability to withstand thermal and mechanical stresses (Hafad et al. 2021). Polycarbonate plastics are widely preferred by consumers and used in many applications due to their versatility in form, colour, shape, mechanical strength, and user-friendliness; hence, they are extensively utilized in the packaging industry. A significant proportion of PC plastics are employed in the food packaging industry, either as polymers or as epoxy resins used as lining materials.

Various studies conducted worldwide have shown that plastic containers can release certain chemicals into food under different conditions, such as cooking, heating, storing, and handling. Chemicals such as dioxins, bisphenol A (BPA), phthalates, and styrene are some of the toxic substances that food may contain if stored in plastics (Muncke et al. 2020; Groh et al. 2021; Kato and Conte-Junior, 2021; Khan et al. 2021; Lerch et al. 2022; Mahlangu et al. 2023). The amount and rate of leaching/migration of such chemicals are largely governed by the temperature and pH of the food, the storage period, the age of the container (new, old, or scratched), and the mode of food processing (Muncke et al. 2020; Alamri et al. 2021; Szabó et al. 2022).

In PC plastics, bisphenol A is one of the essential ingredients added during polymerization. It is well documented that PC plastics can leach BPA, and numerous studies have reported varying concentrations and/or rates of migration of the chemical from PC plastics. There are also reports on the migration of BPA from water containers and various kitchenware. The presence of BPA has been

detected migrating from baby feeding bottles, with its concentrations varying from levels that are undetectable up to the nanogram range (Aschberger et al. 2010; Hoekstra & Simoneau, 2013; Shrinithivihahshini et al. 2014; Johnson et al. 2015; de Quirós et al. 2019; Agarwal et al. 2022).

BPA is potentially a significant endocrine-disrupting chemical (EDC) known to contribute to the development of hormonal disorders such as major depressive disorder (MDD), polycystic ovarian syndrome (PCOS), attention-deficit/hyperactivity disorder (ADHD), autism spectrum disorder (ASD), obesity, cardiovascular diseases, reproductive disorders, and several types of cancer in humans (Abraham and Chakraborty, 2020; Vom Saal and Vandenberg, 2021; Manzoor et al. 2022). The detrimental effects of BPA are primarily attributed to its structural similarity to those of 17-β estradiol, which allows it to interact with estrogen receptors (ERs) or influence estrogen-mediated pathways in other receptors (Maruyama et al. 2013; Mahamuni and Shrinithivihahshini, 2017).

Globally, the incidence of hormone-related disorders and the associated mortality rates are alarmingly high (Lee et al. 2016; Crafa et al. 2021). In India, the incidence of conditions such as infertility, polycystic ovary syndrome (PCOS), thyroid disorders, amenorrhea, hyperprolactinemia, irregular estrous cycles, and contraception issues has been increasing (Krishnamoorthy et al. 2020; Mehreen et al. 2021; Kumar et al. 2024). This increase may be linked to increased exposure to EDCs, including BPA. Several research studies in India have investigated the migration of BPA into food simulants and its presence in environmental samples, highlighting the need for comprehensive assessment and regulation (Shrinithivihahshini et al. 2014; Selvaraj et al. 2014; Agarwal et al. 2015; Kora, 2019; Sharma et al. 2021; Basu et al. 2024).

Previously, various standards devised by the Bureau of Indian Standards (BIS) intended for food contact plastics (listed in Table 1) did not describe any migration tests specifically for BPA. In response to concerns expressed by the scientific community, the BIS drafted a policy in 2013 to standardize the use of BPA in food contact plastics within India (BIS, 2013). In 2017, we highlighted the need for regulations for the use of BPA in food contact plastics (Mahamuni and Shrinithivihahshini, 2017). Unfortunately, the Food Safety and Standards (Packaging) Regulations, 2018, also did not have any specific BPA migration standards but allowed an overall migration limit of 60 mg/kg or 10 mg/dm^2 (IS9845, 1998). Recently, BIS has called for the development of standards for the assessment of BPA from various food-intended packaging and kitchenware. To support further decision-making by the BIS, our present study adopted the standard method IS 9845:1998 for testing materials that migrate from food contact plastics, specifically assessing the migration of bisphenol A from selected food contact plastics. Our findings aim not only to influence policy decisions in India but also to contribute valuable insights to the international scientific community regarding BPA migration, exposure, and public health regulations.

Table 1
List of Indian standards on plastics suitable for use in contact with foodstuffs, pharmaceuticals and drinking water

(Source: IS14972: 2001)

BIS Standard	Title
9845:1998	Determination of overall migration of constituents of plastics materials and articles intended to come in contact with foodstuffs — Method of analysis (second revision)
9833:1981	List of pigments and colourants for use in plastics in contact with foodstuffs, pharmaceuticals and drinking water
10141:1982	Positive list of constituents of polyethylene in contact with foodstuffs, pharmaceuticals and drinking water (1st revision)
10142:1999	Polystyrene (crystal and high impact) for its safe use in contact with foodstuffs, pharmaceuticals and drinking water (first revision)
10146:1982	Polyethylene for its safe use in contact with foodstuffs, pharmaceuticals and drinking water
10148:1982	Positive list of constituents of polyvinyl chloride and its copolymers for safe use in contact with foodstuffs, pharmaceuticals and drinking water
10149:1982	Positive list of constituents of polystyrene (crystal and high impact) in contact with foodstuffs, pharmaceuticals and drinking water
10151: 1982	Polyvinyl chloride (PVC) and its copolymers for its safe use in contact with foodstuffs, pharmaceuticals and drinking water
10171: 1999	Guide on suitability of plastics for food packaging (second revision)
10909: 2000	Positive list of constituents polypropylene and its copolymers for its safe use in contact with foodstuffs, pharmaceuticals and drinking water @rst revision)
10910:1984	Polypropylene and its copolymers for its safe use in contact with foodstuffs, pharmaceuticals and drinking water
11434:1985	Ionomers resins for its safe use in contact with foodstuffs, pharmaceuticals and drinking water
11435:1985	Positive list of constituents of ionomer resins for its safe use in contact with foodstuffs, pharmaceuticals and drinking water
11704:1986	Ethylene/acrylic acid (EAA) copolymers for its safe use in contact with foodstuffs, pharmaceuticals and drinking water
11705:1986	Positive list of constituents of Ethylene/acrylic acid (EAA) copolymers for their safe use in contact with foodstuffs, pharmaceuticals and drinking water
12229:1987	Positive list of constituents of polyalkylene terephthalates (PET & PBT) for their safe use in contact with foodstuffs, pharmaceuticals and drinking water
1224’7:1988	Nylon-6 polymer for its safe use in contact with foodstuffs, pharmaceuticals and drinking water

BIS Standard	Title
12248:1988	Positive list of constituents of Nylon6 polymer for its safe use in contact with foodstuffs, pharmaceuticals and drinking water
12252:1987	Polyalkylene terephthlates (PET & PBT) for their safe use in contact with foodstuffs, pharmaceuticals and drinking water
13449:1992	Positive list of constituents of ethylene vinyl acetate (EVA) copolymers in contact with foodstuffs, pharmaceuticals and drinking water
13576:1992	Ethylene methacrylic acid (EMAA) copolymers and terpolymers for their safe use in contact with foodstuffs, pharmaceuticals and drinking water
13577:1992	Positive list of constituents of ethylene methacrylic acid (EMAA) copolymers and terpolymers in contact with foodstuffs, pharmaceuticals and drinking water
13601:1993	Ethylene vinyl acetate (EVA) copolymers for its safe use in contact with foodstuffs, pharmaceuticals and drinking water
14971: 2001	Polycarbonate resins for its safe use in contact with foodstuffs, pharmaceuticals and drinking water

Materials and Methods

Sample containers

The selection of polymers was guided by the following criteria: (i) polymers containing BPA as a monomer, such as polycarbonate (PC); (ii) polymers where BPA is used as an additive and is widely utilized, such as polyethylene terephthalate (PET); and (iii) polymers marketed as BPA-free, such as polypropylene (PP). Migration tests followed the standard procedures recommended by the Bureau of Indian Standards (BIS), IS 9845:1998, which were originally designed to test overall migrants from plastic materials in contact with food substances. For each polymer type, a set of 16 containers was used to complete the migration tests, except for the alcoholic simulant containers. Alcoholic food simulants (10 and 50%) were not subjected to temperature treatments above 70°C, as alcoholic food substances are not typically treated at such temperatures. Similarly, PET containers were not heated beyond 70°C due to the thermal instability of the polymer and the absence of food substances treated in PET containers at these temperatures. The volumes of the PC, PET, and PP containers were 125 ml, 500 ml, and 750 ml, respectively.

Simulant types and composition

The standard procedure recommends six types of simulants, five of which were used in this experiment. Simulant A was prepared with BPA-free distilled water. Simulant B was created by adding 3% acetic acid (w/v) to an aqueous solution (using Simulant A). Simulant C^1 was made with 10% ethanol (v/v) in an aqueous solution for foodstuffs containing less than 10% alcohol (v/v) (using Simulant A), and Simulant C^2 was made with 50% ethanol (v/v) for foodstuffs containing more than 10% alcohol (v/v) (also using

Simulant A). Freshly distilled n-heptane was used as Simulant D. Simulant type ‘E’ was omitted from this experiment because it has not yet been experimentally developed by BIS. All test conditions were conducted in triplicate, and the temperature and time recommended by BIS are given in Table 2.

Table 2
Simulants for different types of food and temperature–time conditions

Conditions of use	Type of food	Temperature, °C (time, hours) for various Simulants				
		A	B	C^1	C^2	D
High temperature heat sterilized (retorting)	I, II, IV, V and VI	121 (2.0)	121 (2.0)	-	-	66 (2.0)
Hot filled or pasteurized above 66°C	I, II, IV, V and VI	100 (2.0)	100 (2.0)	-	-	49 (0.5)
Hot filled or pasteurized below 66°C	I-VI	70 (2.0)	70 (2.0)	70 (2.0)	70 (2.0)	38 (0.5)
Room temperature filled and stored (no thermal treatment in container) also in refrigerated and frozen condition	I-VI	40 (240)	40 (240)	40 (240)	40 (240)	38 (240)
I	Aqueous, nonacidic foods (pH > 5) without fat					
II	Aqueous acidic foods (pH ≤ 5) without fat					
III	Alcoholic beverages i. Alcohol concentration < 10% ii. Alcohol concentration > 10%					
IV	Oils, fats and processed dry foods with surface fat or volatile oil					
V	Nonacidic (pH > 5) or high fat and having high moisture content					
VI	Acidic foods (pH < 5) or high fat and having high moisture content					
VII	Dry processed foods without fat					
Source: IS 9845:1998						

Sample treatment

The containers were rinsed with BPA-free water at ambient temperature before treatment. They were then filled to their nominal capacity with preheated simulant. The containers were incubated in a water

bath or incubator with an accuracy of ± 1°C. Immediately after the prescribed period, the simulants were transferred to glass containers and allowed to reach ambient temperature before a known volume was extracted for analysis, ensuring that a method blank was maintained for accuracy checks.

Solid-Phase Extraction (SPE)

Silica cartridges filled with C-18 particles (STRATA-E; 500 mg; 3 ml, Phenomenex India Ltd.) were preconditioned with methanol followed by BPA-free water. The treated simulant was passed through the cartridges under vacuum, and after drying, the eluate was collected with methanol, evaporated, and prepared for HPLC analysis.

Silica cartridges prefilled with C^{18} particles were used. The solid phase cartridges were preconditioned with 2 ml of methanol followed by 2 ml of BPA-free water. A known volume of treated simulant was allowed to pass through cartridges under vacuum using a 12-position vacuum manifold (Phenomenex India Ltd.) made of BPA-free PTFE polymer. The flow rate was maintained at approximately 1–2 ml/minute as prescribed by the manufacturer. After passing through the simulants, the cartridges were allowed to dry under a 10 mm Hg vacuum to remove moisture. The elution was carried out by passing 3 ml of methanol twice through glass vials. The eluted methanol was evaporated to dryness under vacuum. The residues were redissolved in 1 ml of methanol and subjected to HPLC analysis.

HPLC Analysis

The samples were analysed using a Waters (USA) high-performance liquid chromatography (HPLC) system equipped with a 2475 quaternary pump and a photodiode array detector (PDA). A reversed-phase column with C^{18} particles was used for chromatographic separation (150 X 4.6 mm *i.d.* 5 µm), and methanol (Qualigens Fine Chemicals Pvt. Ltd., India), and a water mixture was used as the mobile phase at a flow rate of 1 ml per minute. The elution was achieved in isocratic mode at a 70:30 ratio of the mobile phase (methanol/water; *v/v*). The injected sample volume was 20 µl. The target compound found in the test samples was identified at 277 nm (λ_{max}) using the retention time of the external standard used for elution. The chromatograms were processed by using Empower2 (Waters Corporation, USA) software.

Assessment of BPA and Data Analysis

The stock solutions for the standards were prepared by diluting BPA in methanol. A linear curve was obtained from the peak area versus the concentration of these standards, and the quantification of unknown samples was carried out using this calibration curve. SPSS (*v20.0*) was used to determine the linearity of BPA migration among various simulants, and the R (*v3.4.1*) package was used for ANOVA, graphical representations and principal component analysis (PCA). The LOD and LOQ values were calculated from the linear curve ($y = mx + c$) of the concentrations, and the following formula was used for calculations: LOD = 3SD/slope of the curve and LOQ = 10 SD/slope of the curve (Shrivastava and Gupta, 2011).

Results

BPA migration under standardized conditions

The BPA present in the samples was quantified by an external calibration method. Standard BPA concentrations ranging 3–10 ng/ml were used for plotting the standard calibration curve (Fig. 1a). A linear curve was obtained by plotting the analyte concentration against the peak area, and the sample concentrations were derived using the formula $y = mx + c$, where y is the peak area, x is the concentration of the analyte, m is the slope of the curve and c is the intercept. The chromatograms were extracted at 277 nm, and a standard chromatogram is given in Fig. 1b. For the analytical conditions described above, the LOD was 14.12 ng/ml, and the LOQ was 47.07 ng/ml. Except for BPA, which migrated in the *n*-heptane simulant, all the values were well above the LOD.

The BPA migration results in Table 3 are the simulated conditions of food products under five different simulants. Simulant ‘A (water)’ represents aqueous, nonacidic foods (pH > 5) without fat and high fat with high moisture content. A high amount of BPA (539 ng/ml) was detected in samples treated at 121°C for two hours, which is a simulated condition in which the containers were sterilized at high temperature and pressure. The lowest amount of BPA in water was found in the PC samples treated at 70°C for two hours. The water stored at room temperature for 10 days released 243–575 ng/ml, which is greater than that released by the samples treated at 70°C. None of the PP or PET samples released detectable amounts of BPA into the water even at higher temperatures.

Table 3
BPA migrates from food contact plastics, PC, PET and PP into five different simulants, as recommended in IS 9845;1998

Simulant	Treatment	BPA level, ng/ml		
		Polycarbonate (PC)	Polyethylene terephthalate (PET)	Polypropylene (PP)
A	40°C for 10 days	243–575	ND	ND
	70°C for 2 hrs.	32–81	ND	ND
	100°C for 2 hrs.	367–447	ND	ND
	121°C for 2 hrs.	335–539	ND	ND
B	40°C for 10 days	38–43	ND	ND
	70°C for 2 hrs.	43–85	ND	ND
	100°C for 2 hrs.	287–452	ND	ND
	121°C for 2 hrs.	386–528	ND	ND
*C[1]	40°C for 10 days	ND	ND	ND
	70°C for 2 hrs.	270–385	ND	ND
*C[2]	40°C for 10 days	ND	ND	ND
	70°C for 2 hrs.	345–425	ND	ND
D	38°C for 10 days	<LOD	ND	ND
	38°C for 0.5 hrs.	ND	ND	ND
	49°C for 2 hrs.	<LOD	ND	ND
	66°C for 2 hrs.	<LOD	ND	ND
*100°C and 121°C treatments were not performed; LOD-limit of detection; ND-not detectable				

BPA migration in ‘B (3% acetic acid)’ simulated food products such as aqueous, nonacidic (pH ≤ 5) without fat or with a high fat content and a high moisture content. In this treatment, a higher temperature of 121°C for two hours released a high amount of BPA (528 ng/ml), similar to the water simulant. The

lowest amount (38 ng/ml) was released from samples stored at room temperature for 10 days. The amount of BPA released gradually increased with increasing temperature in the 70, 100 and 121°C treatment groups. Using acetic acid as a food simulant, none of the PP or PET samples released any detectable quantity of BPA.

BPA migration in ^{C1} (10% alcohol) and C^2 (50% alcohol) is a simulated condition for food products such as alcoholic beverages. The alcoholic simulants C^1 and C^2 have not been included for high-temperature treatment since food products are not treated and stored under such conditions (100/121°C). Both 10% and 50% alcoholic simulants treated at room temperature and stored for 10 days did not release any detectable amount of BPA. However, 10% alcohol released 385 ng/ml, and 50% alcohol released 425 ng/ml BPA at 70°C for two hours. Alcoholic simulants also did not release BPA from the PP or PET containers. The amount of BPA released in 50% alcohol was slightly greater than that released in 10% alcohol.

BPA migration in D (*n*-heptane) is simulated in food products such as oils, fats and processed dry foods with surface fat or volatile oil. All the BPA levels that migrated from the PC containers in simulant D were below the LOD. BPA (as high as 9 ng/ml) was released from samples treated at 66°C for two hours into *n*-heptane, which is a simulated high-temperature sterilization treatment for oils, fats, dry foods with high surface fat or volatile oils. Simulant D, which was stored at 38°C for 10 days to simulate long storage, released the lowest amount of BPA (3 ng/ml) among all the treated conditions.

Discussion

Influence of Temperature on BPA migration from polycarbonate bottles

Temperature is the key factor influencing the rate at which BPA migration occurs. In our study, BPA migration linearly correlated with temperature. The correlation with this linear trend was highly significant ($P < 0.001$), as shown in Table 4. With increasing treatment temperature, BPA migration also increased, except for in the room temperature treatment group. When stored at room temperature, greater BPA migration (243–575 ng/ml) was found with water stored in PC containers, where the storage time was much greater than that of the other treatment conditions (Fig. 2).

Table 4
Pearson's product-moment correlation between BPA migration from polycarbonate bottles and different temperature regimes

	Correlation at 99% confidence interval	t	df	p value
Temperature and BPA migrated	0.7059873	6.7609	46	$2.082e^{-08}$

The elevated temperature of aqueous media stored in PC containers is attributed to the high rate of BPA release into the media (Nam et al. 2010). In the same study, a rapid increase in BPA migration from PC containers was observed above 80°C. A high amount of BPA (18.47 ng/l) migrated after treatment at 95°C for 30 minutes. The present results were similar to those of the simulant 'A-Water', which was found to have greater BPA migration than the other simulants, and the migration rate greatly increased rapidly in the temperature treatments above 70°C. The amount of BPA that migrated into the water near the boiling temperature in the present study was much greater (367–447 ng/ml). Similarly, the same study by Nam and his coworkers (2010) revealed that PC water containers exposed to direct sunlight (39–42°C) for more than a week released more BPA (8.3–16.8 ng/ml) into the water than did those kept at room temperature (25°C) (3.1–6.2 ng/ml). The findings of our study revealed that temperature increases the rate of BPA migration irrespective of the food simulants used.

Influence of Storage time on the migration of BPA from polycarbonate bottles

Storage time is also a crucial factor influencing BPA migration in aqueous media. The simulants stored for 10 days increased the amount of BPA released compared with the 0.5 h and 2.0 h treatment conditions (Fig. 3). The decrease in the mean BPA concentration after 10 days of storage may have occurred because the number of treatments was lower than that after 2.0 h of storage, which resulted in higher mean values. However, the aqueous simulant stored in PC bottles showed the greatest amount of BPA migration (575 ng/ml). Similarly, in another study, the amount of BPA released from PC containers increased from 311 ± 2.3 to 541 ± 3.1 ng/ml as the storage time increased from 25 h to 50 h, respectively, at 100°C and a pH of 12.1 (Benhamada et al. 2016). In the same experiment, BPA migration increased from 39 ± 1.6 to 55 ± 0.9 ng/ml as the storage time increased from 25 to 50 h at 50°C and a pH of 6.7. These findings revealed that storage time plays a crucial role in influencing the rate of BPA migration from polycarbonate bottles despite differences in pH and temperature.

Influence of food simulants on the migration of BPA from polycarbonate bottles

The mean BPA migration from polycarbonate bottles was found to vary across different types of simulants (Fig. 4). The association was highly significant ($P < 0.001$), as found in the analysis of variance of means of BPA migration with different simulant types (Table 5).

Table 5
Analysis of Variance (ANOVA) of mean BPA migration from polycarbonate bottles across various food simulants

	Df	Sum Sq.	Mean Sq.	F value	Pr(> F)
Simulant	4	714800	178700	6.358	0.000412 ***
Residuals	43	1208575	28106		

The mean BPA migration in aqueous samples was greater than that of the other simulants. This may be due to the hydrolysis effect of polycarbonate containers, which was studied earlier (Torres et al. 2014). Furthermore, hydrolysis mainly occurs in the carbonate group of PC containers treated with temperature, radiation, etc. (Akbay and Özdemir, 2016). In our experiment, aqueous simulant A was also found to have a greater mean BPA migration. In addition to the aqueous simulant, 3% acetic acid increased BPA migration from the polycarbonate bottles. Previously, the simulant pH was reported to influence the rate of BPA migration from PC containers (Benhamada et al. 2016). The present study revealed that the concentration of BPA released into 3% acetic acid in PC containers ranged from 38–528 ng/ml. An earlier study revealed that PC cups released 688.7 ng/ml BPA into 3% acetic acid when treated at 85°C for 10 h and then kept at room temperature for 24 h (Spagnuolo et al. 2017). Similarly, the BPA concentration in canned juice containers ranges from 0.14–28.97 µg/L, which leads to a dietary intake of 0.015 µg/kg bw/day (Khan et al. 2021). These results show that acidic media influence BPA migration in the food substances that are stored. On the other hand, 10% and 50% of the alcoholic simulants, which ranged from 270 to 385 ng/ml and from 345 to 425 ng/ml, respectively, were also found to have significant levels of BPA migration. Minimal quantities of migrated BPA (3–9 ng/ml) were present in n-heptane.

Influence of Temperature and simulant type on BPA migration from polycarbonate bottles

With increasing temperature, all simulants were found to have greater BPA migration, where 3% acetic acid followed by aqueous samples showed greater linearity (Fig. 5). *n*-heptane decreased linearly with increasing temperature, which means that oil-based food substances are less likely to be contaminated with BPA that migrates from PC containers even at higher temperatures. Although the linearity of the alcoholic simulants was much greater than that of the other simulants, it should be considered that boiling temperature (100°C) and sterilization temperature (121°C) conditions were not used.

Influence of Simulant types and Storage time on BPA migration from polycarbonate bottles

Fewer storage times (0.5 h) were used for *n*-heptane simulants at 49°C, resulting in less BPA migrating from PC containers (4–5 ng/ml) (Fig. 6). Under medium storage (2.0 h), BPA released more readily from the PC containers (32–539 ng/ml) for all the simulants except for *n*-heptane (7–9 ng/ml). Under very long storage (240 h) conditions at room temperature, the PC containers released more BPA (243–575 ng/ml) in aqueous simulant and less BPA (38–43 ng/ml) in 3% acetic acid. For the other simulants, there was no BPA migration at room temperature during very long storage.

Influence of Temperature, Storage time and Simulant type on BPA migration from polycarbonate bottles

Principal component analysis (PCA) (R *v3.4.1*) revealed that three sets of components primarily influenced the rate of BPA migration from the polycarbonate containers (Table 6). Furthermore, the first and third components include temperature as the primary factor, and the second component includes storage time as the primary factor. The large number of standard deviations may be attributed to variations in the temperature and storage time.

Table 6
Principal component analysis (PCA) showing three different components and their compositions

	Comp.1	Comp.2	Comp.3
Standard deviation	1.4572681	0.8334390	0.42632058
Proportion of Variance	0.7078768	0.2315402	0.06058308
Cumulative Proportion	0.7078768	0.9394169	1.00000000
Temperature	0.649	-	0.760
Storage time	-0.525	0.744	0.415
Migrated BPA	0.551	0.668	-0.500

Visualization of the PCA components revealed that BPA migration is closely related to temperature and less related to storage time. The results also showed that the simulants differentially contributed to the factor distribution (Fig. 7). The influence of the simulants on the component distribution decreased in the following order: water > 3% acetic acid > alcoholic simulants > *n*-heptane. Acetic acid (3%) is used as a common simulant for foodstuffs such as aqueous, nonacidic (pH ≤ 5) without fat or with high fat and high moisture content. It includes food substances such as fruit juices, vinegar, jams, carbonated beverages, soups, broths, sauces, pickles, ketchup, cheese, and milk sweets. In the NHANES 2003–2008 study conducted in the US, urinary concentrations of BPA were strongly associated with specific canned foodstuffs such as vegetables, fruits, soups, juices and beverages (Hartle et al. 2016).

In our experiment, both acidic and nonacidic aqueous simulants released considerably more BPA than did the alcoholic simulants. Infant formula analyses have shown that regardless of package type, BPA migrates into milk powder at concentrations ranging from 3 to 375 ng/g (Cirillo et al. 2015). The equivalent simulants used in the present study, water (A), released as much as 539 and 447 ng/ml at 121°C and 100°C, respectively. This finding implies that raw milk is also contaminated with PC baby bottles that are filled with milk at elevated temperatures. BPA is not a component in the polymerization of PP or PET, yet studies have reported the presence of BPA in PET containers (Guart, et al. 2011; Shao et al. 2005). However, the PET and PP containers treated with the BIS standard in this study did not leach any detectable BPA into any of the food simulants. Similarly, for polypropylene, in addition to PES, PA, Triton and silicone containers did not release any BPA when treated with 50% alcoholic simulant at 70°C for 2.0 h (Onghena et al. 2016). According to the food types classified by this BIS method and from the results, the following food products that come in contact with polycarbonate plastic food substances are

more at risk for BPA contamination: (i) aqueous food substances filled and stored under refrigerated or frozen conditions for longer durations, such as mineral water, honey, sugar syrups and skim milk, and (ii) aqueous food substances such as milk sterilized/stored under high-temperature conditions. Although other food matrices, such as alcoholic and acidic food matrices, are vulnerable to BPA contamination, such food materials are less likely to be processed at higher temperatures. Although the exposure and dietary intake calculations from various studies, similar to our study, are less than any observable adverse effect, monitoring the migration of BPA under various storage and treatment conditions is essential (Khan et al. 2021; Lestido-Cardama et al. 2021; Vázquez-Loureiro et al. 2023).

Conclusion

The BIS standard for testing chemical migrants from food contact plastics, IS9845:1998, was adopted for the assessment of bisphenol A migration from polycarbonate, PET and polypropylene plastic containers. BPA was only released in the polycarbonate containers, and no BPA was detected in the PET or polypropylene containers by the HPLC system. Temperature was found to be the key factor influencing BPA migration at higher rates from PC bottles. Compared to those of acidic (3% acetic acid) and fatty (*n*-heptane) food simulants, BPA migration was greatest in the aqueous simulant. *n*-heptane was less likely to be contaminated with BPA that migrated from PC containers even at higher temperatures. A considerable amount of BPA migrated from PC containers to alcoholic food simulants. From the results, it can be concluded that aqueous foods are more vulnerable to BPA contamination when they are treated at elevated temperatures and/or stored in PC containers for a long time.

Declarations

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions

ND Shrinithivihahshini supervised and mentored the work and reviewed the manuscript; D Mahamuni performed the formal analyses, curated the data, wrote the original draft and edited the draft based on inputs from ND Shrinithivihahshini.

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Data Availability Statement

The author confirms that all data generated or analysed during this study are included in this published article. Furthermore, secondary sources and data supporting the findings of this study were all publicly available at the time of submission.

Ethical Approval

This work does not require any ethical approval.

Consent to participate

Not applicable.

Consent for publication

Not applicable.

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Figures

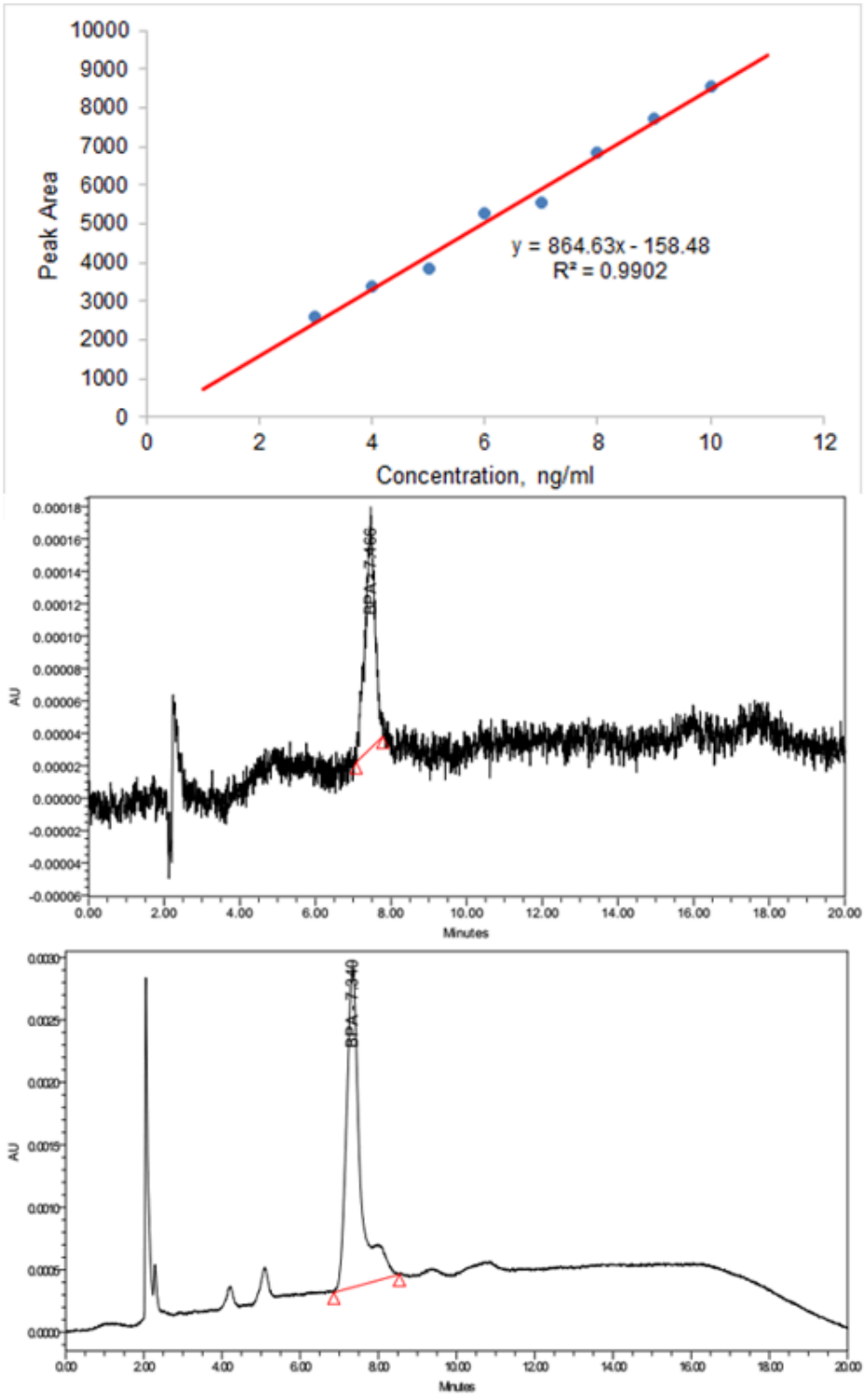

Figure 1

(a) Linear curve of external calibration standards. (b) Chromatogram showing the peak for the BPA standard.(c) Chromatogram showing the presence of BPA that migrated from a PC sample.

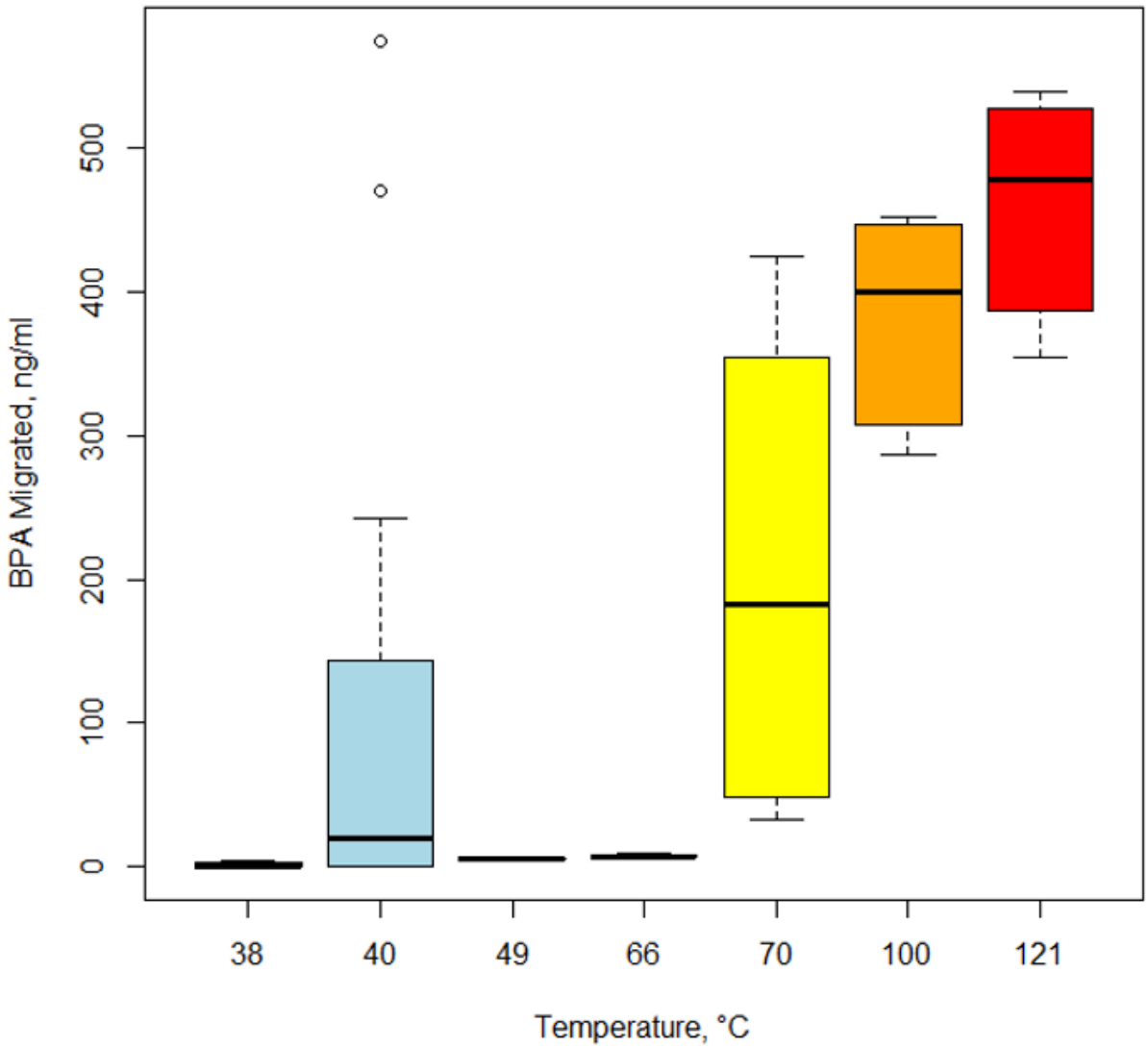

Figure 2

Boxplot showing BPA migration from polycarbonate bottles across different temperature regimes

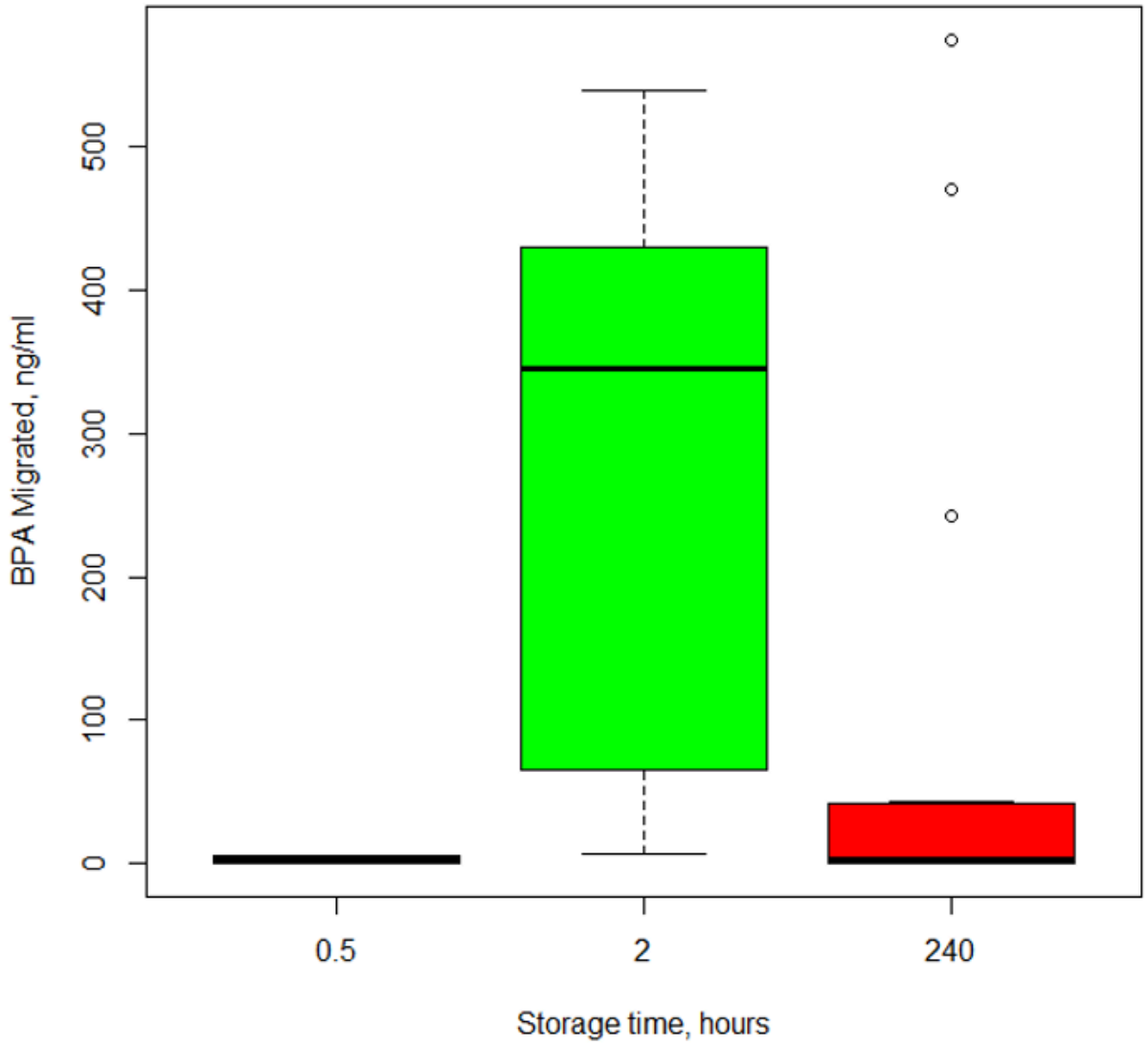

Figure 3

Boxplot showing BPA migration from polycarbonate bottles across different treatment time regimens

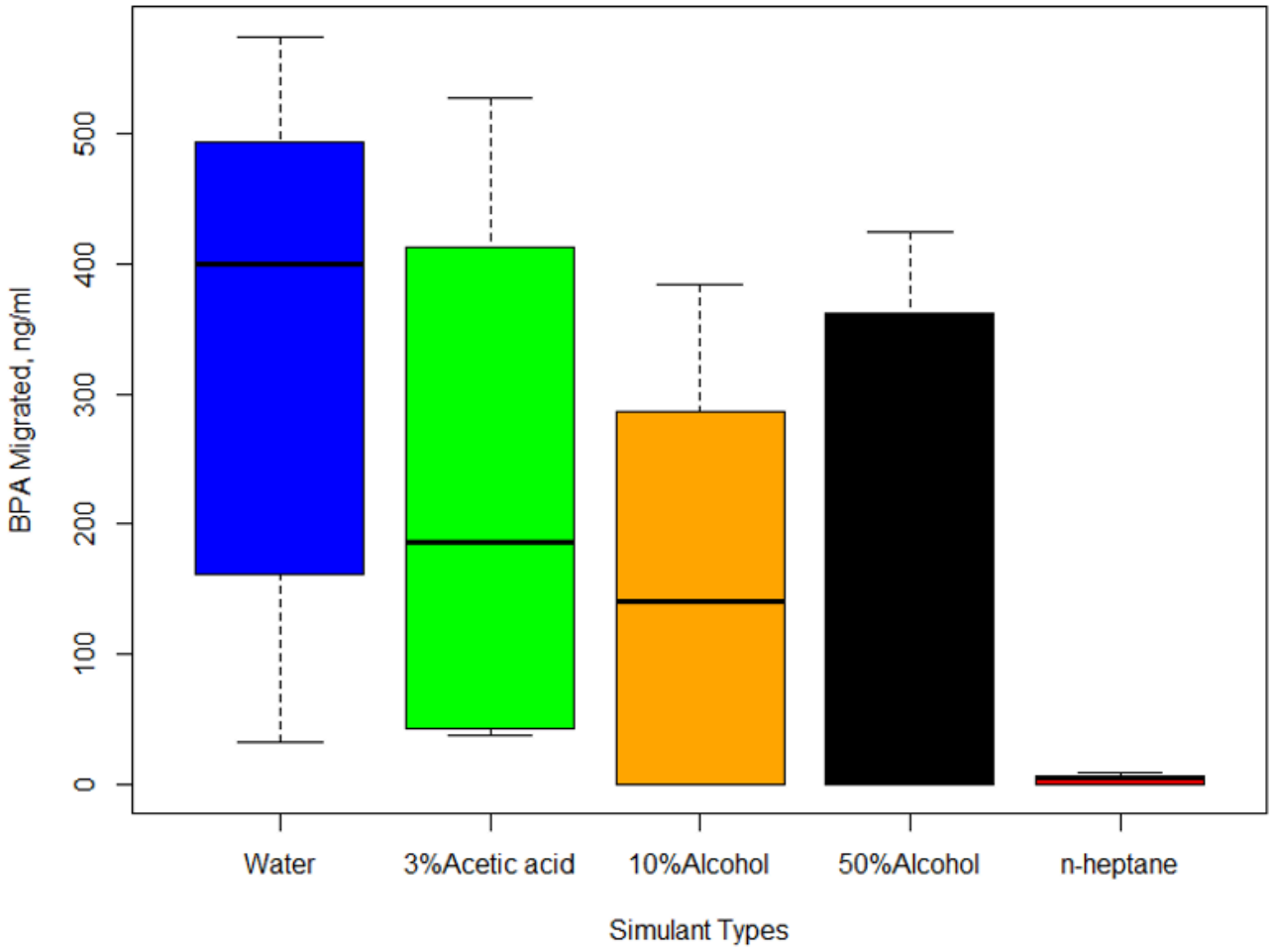

Figure 4

Boxplot showing BPA migration from polycarbonate bottles to different simulants

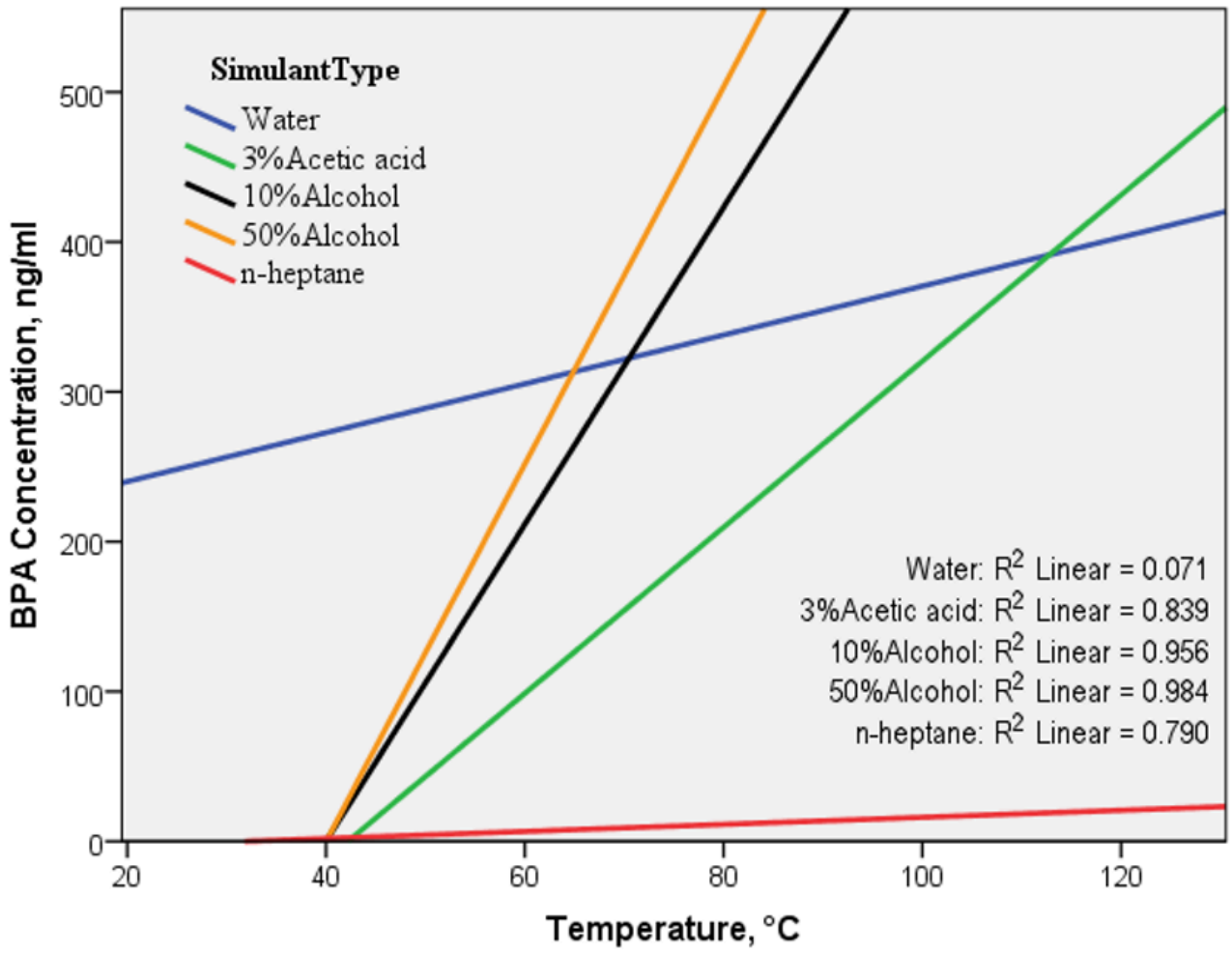

Figure 5

Plot showing mean BPA migration from polycarbonate bottles across different simulant and temperature conditions treated in this study

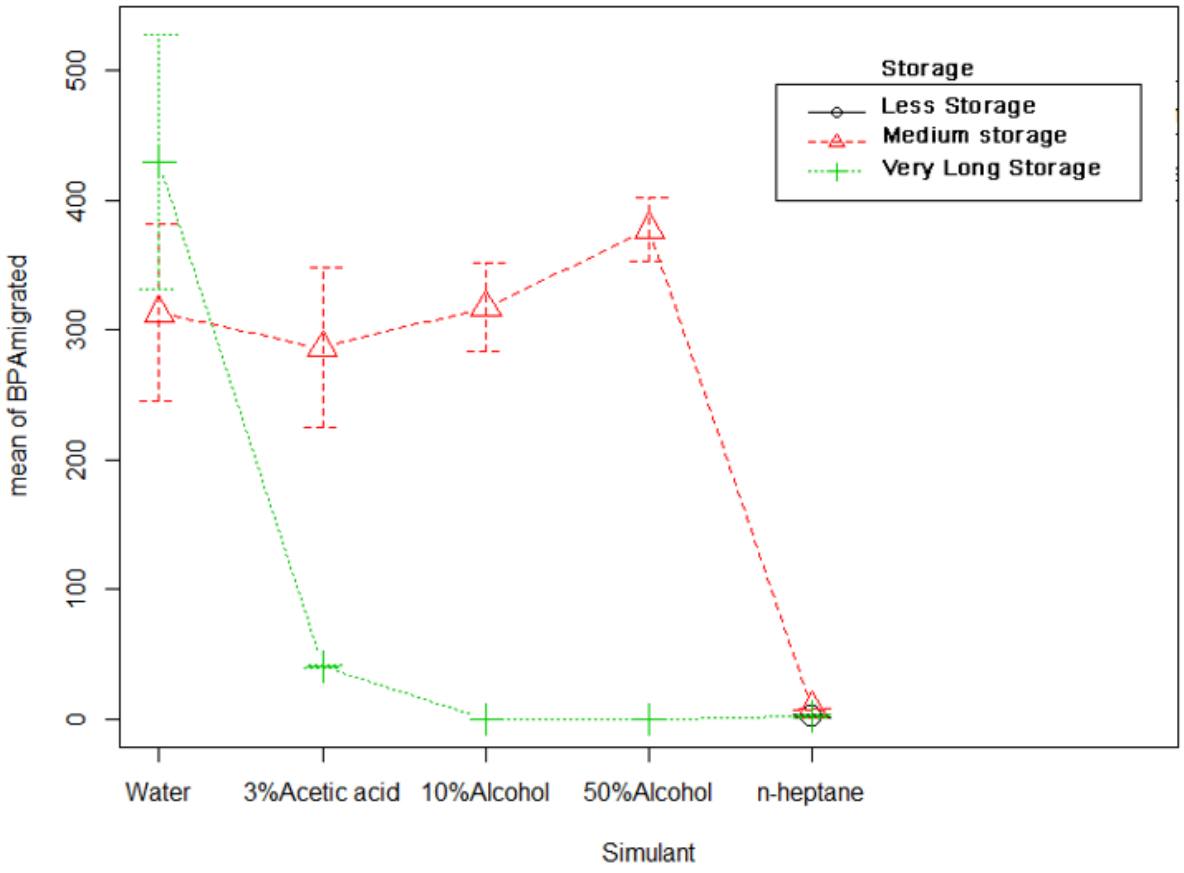

Figure 6

Plot showing mean BPA migration from polycarbonate bottles across different simulants and storage time conditions treated in this study

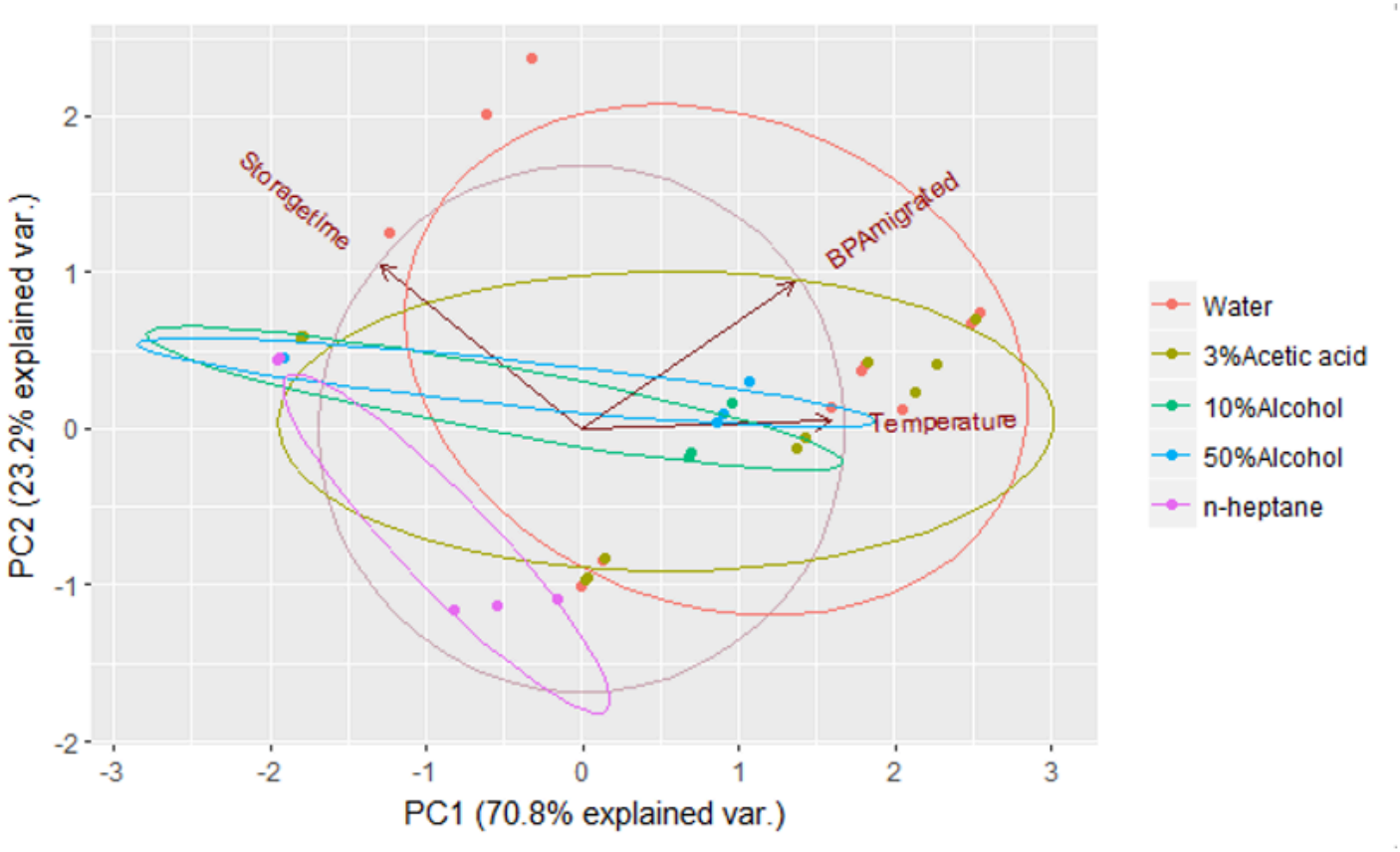

Figure 7

Plot showing mean BPA migration from polycarbonate bottles across different simulants and storage time conditions treated in this study