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Migration of total UV-absorbing contaminants from Philippine polypropylene microwavable containers: Effects of food simulant, contact time, and temperature

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ABSTRACT
This study evaluated the migration of total UV-absorbing contaminants (TACs) from polypropylene (PP) microwavable containers in the Philippines under food-contact conditions relevant to regulatory screening and local use. Previously developed UV-Vis spectrophotometric methods for polyethylene (PE) food packaging were applied to PP matrices using water and 20 % ethanol as simulants for aqueous and alcoholic foods. Migration profiles were then compared with earlier data for fatty and oily foods, while selected PP samples were subjected to varying contact times and temperatures. The results showed that TAC migration from PP microwavable containers remained below the FDA Philippines maximum allowable limits (MALs). Absorbance values were strongly and positively correlated with both contact time and temperature. The findings extend previous screening studies by broadening the range of food simulants and contact conditions evaluated and by providing additional evidence for risk-based assessment of plastic food contact articles in the local setting. Further work should include acidic and dry food simulants, compound-specific identification, longer storage simulations, and direct microwave exposure studies.

Section: RESEARCH PAPER

Keywords: chemical migration; food contact article; food packaging; microwavable; polypropylene (PP); total UV-absorbing contaminants (TACs)

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1. INTRODUCTION

Plastic food-contact articles may represent underexamined sources of chemical exposure, because substances present in the materials may migrate into food during transportation, storage, reheating, or consumption [1]. Chemical migration is influenced by polymer structure [2], additive chemistry [3], molecular size [4], food composition, temperature, and duration of contact [5]–[8]. These factors are particularly relevant for polypropylene (PP) microwavable containers used for ready-to-eat and reheated foods, where elevated temperatures and prolonged contact conditions may enhance the release of intentionally added substances (IAS) and non-intentionally added substances (NIAS) [9]–[15].

PP is widely used in microwavable packaging because of its thermal stability, mechanical durability, affordability, and suitability for takeaway foods and reheating applications [16]–[18]. PP containers are used in the Philippines for a wide range of acidic, alcoholic, aqueous, fatty or oily, and low-moisture foods [19]. These varied food types may interact differently with plastic food contact articles [20]–[21]. Therefore, evaluating migration behavior across representative food simulants is necessary to determine whether locally available PP containers remain suitable under conditions that reflect actual consumer use [22]–[24].

Quantitative migration studies are useful for generating preliminary evidence on the safety and performance of plastic food contact articles [25]. Total UV-absorbing contaminants (TACs), measured through UV-Vis spectrophotometry, do not identify individual chemical migrants but provide a practical screening indicator for the presence of migrating UV-active substances [26]. Along with the Japan External Trade Organization (JETRO) methods for total residual contaminants (TRCs) and total oxidizable contaminants (TOCs) [27], TAC determination can support method comparisons [28]–[29], profiling [30], and regulatory prioritization [31], particularly in contexts where compound-specific datasets remain scarce. Previous Philippine studies have examined TAC migration from polyethylene (PE) packaging to different simulants [32]–[34] and at varying temperatures [35]–[36]. However, available local evidence remains insufficient to describe how PP microwavable containers behave across different food simulants (particularly with polar media) and to changing contact conditions (i.e., increasing time and temperature) [37].

The current status of national policies on food-contact article safety further strengthens the need for locally generated migration data. The Philippine regulatory framework continues to evolve, particularly when compared with international systems that have more comprehensive requirements for migration testing, compliance assessment, and market surveillance [26], [38]–[40]. Existing policies issued by the Food and Drug Administration (FDA) Philippines currently cover bisphenol A in infant feeding bottles and sippy cups [41], as well as voluntary certification guidelines for food-contact articles [42]. However, broader mandatory testing and systematic monitoring remain constrained despite emerging evidence of chemical migration [36]–[37]. Continuous local research on food-contact article safety can therefore provide additional scientific information for risk-based regulatory discussions, product assessments, and possible collaborations among laboratories, industry stakeholders, and policymakers.

This study builds on previous research by extending TAC screening of locally available PP microwavable containers beyond fatty and oily food simulants. Specifically, the study aims to (a) evaluate the applicability of TAC screening methods previously developed for PE samples to PP matrices; (b) determine the migration from commercially available PP microwavable containers using water and 20 % ethanol as representative simulants for aqueous and alcoholic foods, respectively; (c) compare these findings with earlier results for fatty and oily food simulants; and (d) examine preliminary effects of contact time and temperature on TAC migration. By clarifying the influence of the simulant type, contact time, and temperature, this study provides measurement evidence to support the development of baseline research, the strengthening of local policies, and the routine monitoring of PP food-contact articles in the Philippine market.

2. METHODOLOGY

2.1. Method robustness

To evaluate the applicability to PP matrices, the procedures developed and validated by Ting et al. [34] and Mendoza et al. [32] for TACs migrating from PE into aqueous and alcoholic food simulants, respectively, were adopted. Preliminary screening was performed to estimate TAC migration from PP samples. For each food simulant, an equal number of units of representative PE and PP samples with comparable AU values were analyzed and evaluated using appropriate statistical tests.

2.2. Sample profiling

Various brands of microwavable food containers were purchased from markets across Metro Manila and nearby provinces, using the same codes and geographic locations as in the previous research [37]. For each food simulant, three (3) units from each collected PP sample were cut into 5 cm × 10 cm sections, wiped with lint-free paper, and placed in separate beakers using tweezers. Approximately 100 mL of food simulant was added to each beaker, ensuring complete immersion. Water was used as the simulant for aqueous foods, while 20 % ethanol was used to represent alcoholic products. The beakers were covered with glass plates and maintained at 49 °C for 24 hours in a Memmert oven. After extraction, the replicates were removed, and the resulting solutions were analyzed separately using a Shimadzu UV-1800 UV–Vis spectrophotometer, scanning across the 220–360 nm wavelength range. Absorbance data were recorded and statistically processed.

2.3. Time and temperature variations

Using the method validated for assessing TAC migration from PP into n-heptane (fatty and oily food simulant) [37], several units of the PP container that exhibited the highest AU were purchased and subjected to two experimental conditions. In the first condition, temperature was kept constant at 22–28 °C, while contact time was varied at 15, 30, 60, 90, and 120 minutes. Meanwhile, in the second condition, contact time was kept constant at 30 minutes, while temperature was varied at 0, 4, 28, 40, and 66 °C to simulate fatty and oily foods in PP containers subjected to freezing, refrigeration, and elevated temperatures, respectively.

3. RESULTS AND DISCUSSION

3.1. Method robustness

The preliminary screening of TAC migration from microwavable containers into aqueous food simulant showed that PP-0002 had an absorbance value (0.027 AU) comparable to PE-1001 (0.021 AU), a polyethylene bag obtained from a local manufacturer and previously analyzed. Table 1 summarizes the statistical analysis and significance testing of ten replicates, for both PP-0002 and PE-1001.

The equal-percent recoveries not only indicate excellent accuracy but also suggest similar polymer responses. However, the relative standard deviations (%RSD) are above the repeatability criterion of 5 %, commonly applied in analytical measurements [43]. This may imply material inhomogeneity, often as an inevitable result of the manufacturing process and post-production conditions [28], [34], [36]. Interventions such as collaborating with manufacturers to produce homogenous samples or spiking matrix mixtures [44] may be employed in the future. Nevertheless, %RSD values below 10 % or 20 % are generally acceptable to the industry [45]–[46].

The Shapiro-Wilk test conducted on both data sets satisfied the criterion for normal distribution, while Levene's test supported the assumption of equal variances, with p-values greater than 0.05 for both tests. Consequently, the independent

Table 1. Statistical comparison of representative PP and PE samples showing no significant difference in TAC recovery from polymers exposed to aqueous and alcoholic food simulants, supporting the robustness of methods developed by Ting et al. [34] and Mendoza et al. [32].

	n	Mean AU	Mean %Recovery	SD	%RSD	Shapiro–Wilk test, *p*	Levene's test, *p*	Significance test		
								df	$\lvert t \rvert$	*p*
in water								Independent t-test		
PP-0002	10	0.026	100	10.8	10.8	0.100	0.240	18	5.15×10^{-5}	1.00
PE-1001	10	0.018	100	5.80	5.80	0.191				
in 20 % ethanol								Welch's t-test		
PP-0014	8	0.026	100	6.63	6.63	0.563	0.032	14	0.00	1.00
PE-1001	8	0.011	100	11.7	11.7	0.088				

t-test results ($t < t_{\text{crit}}$ (2.101) for $df = 18, p > 0.05$) indicated no statistically significant difference between the percent recoveries of PP-0002 and PE-1001 in the water simulant. This finding suggests that Ting et al.'s validated method for determining TAC migration from PE into aqueous food simulant [34] may also be applicable to PP, demonstrating method robustness under evaluated conditions.

The preliminary screening of TACs from microwavable containers into alcoholic food simulant showed that PP-0014 had an absorbance value (0.026 AU) closest to PE-1001 (0.011 AU). The corresponding statistical analysis and significance testing of eight replicates, for both PP-0014 and PE-1001, are also summarized in Table 1.

Extraction in 20 % ethanol also resulted in equal-percent recoveries for the representative PP and PE samples, indicating excellent accuracy and similar polymer responses. The calculated %RSD values were also above the laboratory criterion of 5 %, but still below the 20 % threshold acceptable to the industry.

The normality assumption was satisfied based on the Shapiro–Wilk test. However, the homogeneity of variances was not supported by Levene's test ($p < 0.05$), implying unequal variability between the two polymer groups and the need for a different statistical test. Welch's t-test was employed, yielding a t-statistic below the critical t-value of 2.145 for a combined data set with 14 degrees of freedom (df), and a p-value greater than the typical significance threshold of 0.05. As a result, no statistically significant difference was observed between the percent recoveries of PP-0014 and PE-1001 in 20 % ethanol. This finding suggests that Mendoza et al.'s validated method for determining TAC migration from PE into alcoholic food simulant [32] may also be applicable to PP, demonstrating method robustness under evaluated conditions.

3.2. Sample profiling

The absorbance values (AU_{mean}) and standard deviations (SD) corresponding to TAC migration from commercially available microwavable containers in Metro Manila into three different simulants are summarized in Table 2.

Results for both water and 20 % ethanol showed that none of the samples analyzed exceeded the 0.300 AU maximum allowable limit (MAL) set by the FDA Philippines for aqueous and alcoholic foods, respectively. The highest absorbance values with water (0.082 AU) and 20 % ethanol (0.069 AU) correspond to approximately 27.3 % and 23.0 % of the MAL, respectively. These results suggest that all tested PP microwavable containers complied with the MAL under the evaluated conditions.

The detection of TAC migration in water and 20 % ethanol is consistent with recent safety assessments conducted on polypropylene food containers. Apart from microplastics, volatile organic compounds (VOCs), such as saturated and unsaturated hydrocarbons and fatty acyls, were identified from PP self-heating containers [47]. Since these compounds are largely non-polar, they are more likely to migrate into fatty and oily food simulants such as olive oil, 95 % ethanol, and n-heptane, as observed in the previous study [37]. However, other VOCs detected, such as phenol ethers, organooxygen compounds, [47] and organophosphate esters [48], exhibit a wide range of polarities depending on their chemical structures. This supports the interpretation that migration behaviour is also influenced by the chemical nature of a compound including its polarity, solubility, and affinity for the contacting food, [20]–[21], [49]. It also supports the possible transfer of some substances into polar media, such as water and 20 % ethanol, as demonstrated by PP-0010.

Notably, both 0.082 AU and 0.069 AU were recorded from the same microwavable container brand (PP-0013), which also showed the highest absorbance for fatty and oily foods (0.199 AU) in the previous study [37]. This suggests a possible need to further examine the raw material selection, additive composition, and production processes associated with PP-0013. A recent review conducted by Muzeza et al. found that monomers tend to migrate into food because some remain unreacted after polymerization, or are not incorporated into the polymer chain. As a result, these free monomer units can diffuse through the polymer matrix and interact with food, potentially contributing to safety concerns [50]. Another study by Conchione et al. showed that polyolefin oligomeric hydrocarbons (POHs), which are mainly considered as non-intentionally added substances (NIAS), also migrate in substantial amounts from polypropylene containers to food. These POHs are formed either as side-reaction products during the manufacturing process, or as residues retained in the polymer, and may be released under favourable conditions [51]. Additionally, Liu et al. examined the effect of using recycled PP (rPP) on the chemical migration of processing aids such as antioxidants, ultraviolet (UV) absorbers, nucleating agents, plasticizers, flame retardants, slip agents, antistatic agents, and bactericides into food simulants and milk. These processing aids are released because the properties of rPP (e.g., thermomechanical aging degradation and polymer mix incompatibility) make them weaker than their virgin counterparts [52].

Comparing sample responses across the three simulants showed an observable trend in 88.9 % of the analyzed PP samples: chemical migration was higher when the samples were in contact with n-heptane. Meanwhile, no definitive generalization can be made regarding migration differences between the two polar simulants, except that approximately 66.7 % of the analyzed samples exhibited higher absorbance values when in contact with 20 % ethanol than with water. Only

Table 2. Mean absorbance values (AU_{mean}) and standard deviations (SD) for representative PP microwavable containers indicating that TAC migration was generally highest in the least polar simulant, n-heptane, followed by 20 % ethanol and water, across most tested brands. None of the tested samples exceeded the FDA Philippines maximum allowable limit for water and 20 % ethanol food simulants, whereas exceedances were observed under n-heptane conditions.

Sample code	n-heptane		water		20 % ethanol	
	AU_{mean}, n = 3 [37]	SD	AU_{mean}, n = 3	SD	AU_{mean}, n = 3	SD
PP-0001	0.084	0.002	0.013	0.003	0.024	0.001
PP-0002	0.083	0.005	0.021	0.001	0.029	0.002
PP-0003	0.140	0.003	0.044	0.004	0.030	0.003
PP-0004	0.083	0.001	0.024	0.002	0.042	0.003
PP-0005	0.068	0.008	0.013	0.001	0.030	0.002
PP-0006	0.036	0.004	0.040	0.005	0.041	0.004
PP-0007	0.035	0.003	0.017	0.003	0.038	0.00
PP-0008	0.058	0.006	0.019	0.002	0.028	0.002
PP-0009	0.124	0.005	ND	-	0.045	0.00
PP-0010	ND	-	0.063	0.006	0.025	0.003
PP-0011	0.048	0.001	0.015	0.002	0.019	0.002
PP-0012	0.107	0.005	ND	-	0.037	0.001
PP-0013	0.199	0.004	0.082	0.006	0.069	0.002
PP-0014	0.110	0.004	0.033	0.00	0.013	0.001
PP-0015	0.078	0.002	ND	-	0.024	0.002
PP-0016	0.043	0.001	NA	-	NA	-
PP-0017	0.045	0.004	0.027	0.004	0.019	0.007
PP-0018	0.086	0.003	0.017	0.002	0.027	0.002
PP-0019	0.028	0.002	NA	-	NA	-
PP-0020	0.097	0.006	NA	-	NA	-
PP-0021	0.043	0.004	0.020	0.001	0.020	0.002
Method detection limit (MDL)	0.009	-	0.013	-	0.005	-
FDA Philippines Maximum allowable limit (MAL)	0.100	-	0.300	-	0.300	-

Legend: NA = not available; ND = not detected

PP-0021 demonstrated similar responses to both water and 20 % ethanol. Descriptive statistics suggest that chemical migration from PP can be ranked by mean absorbance as water < 20 % ethanol < n-heptane in 47.6 % of the total samples. The increase in absorbance values with decreasing polarity may imply that most of the migrants present in commercially available PP have the highest affinity towards fatty and oily foods.

3.3. Comparison of TAC migration from PE and PP brands

Alejandro et al. reported a larger proportion of PE packaging (60.0 %) that exceeded the MAL for n-heptane [36], compared with PP containers (23.8 %) purchased from Metro Manila and neighboring provinces [37]. Although the total number of brands differed between the two studies ($n_{\mathrm{PE}} = 15; n_{\mathrm{PP}} = 21$), adding six PE brands without detectable values would reduce the percentage to only 42.9 %. Thus, based on TAC profiling, most of the tested PP brands showed a lower exceedance rate than the previously analyzed PE brands under n-heptane conditions.

In contrast, PE and PP samples from comparable collection sites did not exceed the FDA Philippines MAL for articles in contact with aqueous food simulant, as reported by Ting et al. for PE [34] and by the present study for PP. Moreover, the current results showed that 83.3 % of the PP containers exposed to water simulant yielded values above the method detection limit (MDL), whereas only 40.0 % of PE brands demonstrated detectable TAC migration under comparable conditions. Adding six PE brands with values would increase the PE detection rate only to 57.1 %. This value would remain below the percentage of PP brands with detectable TAC migration, regardless of the future availability and measured absorbance values of PP-0016, PP-0019, and PP-0020. Therefore, based on the findings, most of the tested PP brands exhibited a higher detection rate than PE brands for TAC migration into aqueous food simulant, although all measured values remained below the regulatory threshold.

Additionally, mean absorbance values for PP brands with detectable TAC migration into water ranged from 0.013 to 0.082 AU. This interval is approximately five times wider than that observed for PE brands with detectable TAC migration in water, which ranged from 0.017 to 0.031 AU [34]. Nevertheless, these estimates may change as more brands are assessed in future studies.

3.4. Time and temperature variations

Figure 1 and Figure 2 show the effects of varying contact times and temperatures, respectively, on the TAC migration from PP-0013 into n-heptane, while maintaining all other parameters constant. The computed correlation coefficients, R, were 0.975 for absorbance values versus time, and 0.856 for absorbance versus temperature. Both values indicate strong positive correlations [53] and suggest that, as either extraction time or temperature increases, absorbance also increases. These findings support previous reviews [20], [21] and several simulations that examined the effects of both factors.

Most thermal studies on PP packaging report enhanced diffusivity and changes in compound solubility as contact temperature increases, thereby increasing migration rates. Petrovics et al.'s research on the effects of elevated temperatures on PP reported behaviour resembling plasticization. Consequently, the swelling promotes the migration of additives [54], which may increase the total amount of contaminants migrating from PP packaging into the contacting product. A more recent study by Massahi et al. examined the release of

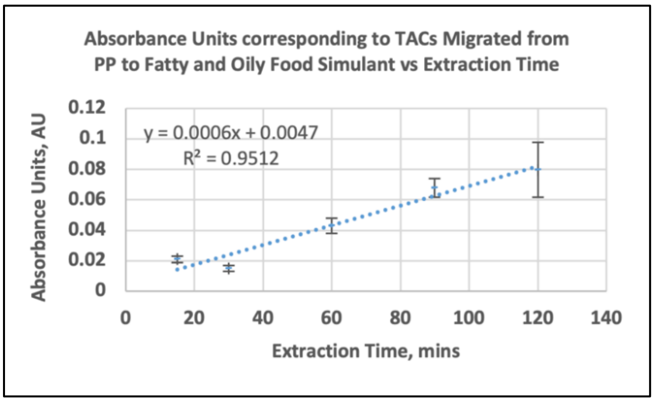

Figure 1. The absorbance values of PP-0013 showed a strong positive correlation (R = 0.975) with extraction time within the 15–120-minute exposure period, indicating that longer contact duration promoted greater TAC migration into n-heptane.

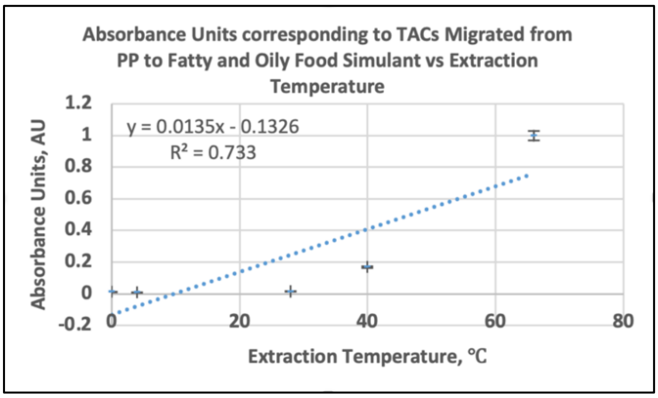

Figure 2. The absorbance values of PP-0013 showed a strong positive correlation (R = 0.856) with extraction temperature across the 0–66 °C interval, suggesting that higher contact temperatures promoted greater TAC migration into n-heptane. This range was selected to approximate locally relevant handling and use conditions, including freezing, refrigeration, ambient exposure, and moderately elevated heating.

endocrine-disrupting chemicals (EDCs) from PP. Solid-phase extraction (SPE) and gas chromatography-mass spectrometry (GC-MS) allowed the measurement of UV-absorbing contaminants such as di(2-ethylhexyl) phthalate (DEHP), dibutyl phthalate (DBP), benzyl butyl phthalate (BBP), bisphenol A, and nonylphenol contained in cups and containers and released to distilled water at high temperatures (40–100 °C) [55], covering a wider temperature range than that evaluated in the present study.

Temporal studies, while scarcer than temperature-dependent experiments, affirm the effect of prolonged contact on the chemical migration from PP containers. A study reported by the Food and Agriculture Organization of the United Nations investigated the influence of time on the migration of phthalate esters from PP. The study concluded the active role of PP in the migration of these compounds, with DEHP having the highest value on the fourth month [56]. A separate study by Djuhriah et al. used a shorter time frame, but on PP cups containing water and exposed to 80 °C to mimic hot beverages. Findings showed increasing amounts of styrene but decreasing amounts of phthalic acid from 20 to 40 minutes [57]. Overall, these studies indicate that chemical migration from PP can occur under different time and temperature conditions.

4. CONCLUSION AND RECOMMENDATIONS

This study extends previous Philippine research on TAC migration from polypropylene microwavable containers by evaluating additional food simulants and examining the influence of contact time and temperature. Significance testing supports the use of previously developed methods for PE to PP matrices. The findings indicate that TAC migration from the tested PP containers remained below the MAL for aqueous and alcoholic food simulants. Comparison across simulants further suggests that migration behaviour is affected by the nature of the contacting medium, with greater apparent migration under less polar, fatty, and oily simulant conditions. The observed time- and temperature-dependent trends also support the importance of considering actual handling, storage, and reheating conditions when assessing plastic food-contact articles.

The study provides additional measurement evidence for the risk-based assessment of PP microwavable containers in the Philippine market. Its practical value lies in supporting baseline data generation, product profiling, and future regulatory discussions on food-contact article safety. For laboratories and regulators, the findings demonstrate the usefulness of TAC screening as a preliminary tool for identifying products and contact conditions that may require closer evaluation. For manufacturers and other stakeholders, the results may guide material selection, product improvement, and further safety verification under relevant food-use conditions.

Future studies should expand the assessment to other locally used plastic materials, including polyethylene terephthalate (PET), polyvinyl chloride (PVC), polycarbonate (PC), recycled plastics, and bio-based alternatives. Additional testing should also include acidic and dry food simulants, longer storage durations, repeated-use scenarios, post-cooking conditions, and direct microwave exposure to better approximate consumer practices. As TAC screening does not identify individual migrants, compound-specific analyses using complementary chromatographic or mass spectrometric techniques are recommended to determine the chemical identity, source, and possible toxicological relevance of migrating substances. Finally, products showing elevated and nonconforming migration should be prioritized for stakeholder engagement, reformulation studies, and follow-up safety assessment to strengthen packaging safety and regulatory preparedness in the Philippines.

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