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RESEARCH ARTICLE

# Aromatic amine migration from commonly used kitchen utensils marketed inTurkey: detection and quantification using LC-MS/MS

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**ABSTRACT**

Primary aromatic amines (PAAs) are migrants, some of which are carcinogenic and classified by official organizations such as IARC Program. Consumers prefer kitchen utensils made of plastic, especially polyamides, for their ease of use and durability. Fifty-five samples of kitchen utensils were collected by retailers in Turkey. They were made of polyamide (40 samples), polypropylene (5 samples), polytetrafluoroethylene (5 samples), polyethylene (4 samples) and polystyrene (1 sample). Twenty targeted PAAs were analyzed in migration extracts using LC – MS/MS. Six PAAs-aniline (ANL), 4,4′-methylenedianiline (4,4′-MDA), 2,6-toluenediamine (2,6-TDA), 2,4-toluenediamine (2,4-TDA), 3,3′-dimethylbenzidine (3,3′-DMB), and o-toluidine (o-T) were detected in at least one of the 55 samples. ANL was the predominant PAAs in 20 samples below and above its limit of quantification (LOQ) values. The serving spoon (SS3 coded sample) had the highest aniline concentration at 0.057 mg/kg, followed by the crepe spatula (CS3) at 0.038 mg/kg. 4,4′-MDA and 3,3'-DMB were detected below their LOQ values in four and only one of the samples. After the third migration test, no PAAs were detected in any sample. The detected PAA concentrations were low, suggesting a limited potential health risk for consumers under the tested migration conditions, although the presence of PAA highlights the importance of continued monitoring.

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## Introduction

Food contact materials (FCMs) encompass a broad range of materials and articles intended to come into contact with food at various stages of the supply chain, including processing, packaging, storage, preparation, and serving (Muncke et al. 2017; Carvalho et al. 2022; Galbiati et al. 2022; Gheni et al. 2023; Zahir et al. 2024). Among these, polyamides (PAs) are extensively used in kitchen utensils and food packaging due to their durability, heat resistance, and non-scratch properties (Tsochatzis et al. 2023).

Despite these advantages, FCMs-especially polyamide-based utensils-can pose chemical safety concerns because they may migrate hazardous substances into food. Of particular concern is the migration of primary aromatic amines, which can originate from residual monomers, polymerization by-products, or certain colorants (Trier and Granby 2015; Niklas et al. 2023). Several PAAs, including 4,4′-methylenedianiline and aniline, are classified as potentially carcinogenic to humans by the International Agency for Research on Cancer (IARC 2021) and therefore represent compounds of substantial toxicological concern (Yavuz et al. 2016; Chmielewski et al. 2021).

Previous studies have reported the occurrence and migration of PAAs from polyamide kitchen utensils, frequently identifying aniline and 4,4'-Methylenedianiline as the most prevalent compounds. Migration levels reported in the literature vary widely and, in some cases, exceed regulatory thresholds, indicating potential non-compliance and consumer exposure risks (Sanchis et al. 2015; Perez et al. 2019; Arrizabalaga-Larrañaga et al. 2022; Szabó et al. 2024). These findings highlight the need for continued surveillance of PAAs in FCMs and improved understanding of factors influencing their migration behavior.

Kitchen utensils sold in Turkey include domestically manufactured products and imported items, subject to varying regulatory controls at the point of production. In 2024, Turkey's imports

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originated from diverse partners, including China, Russia, Germany, Italy, and the United States, illustrating the market's mix of imported goods alongside local production. Consequently, the Turkish market may be broadly representative of products available in other regions with mixed sourcing, while also reflecting market-specific conditions related to enforcement and quality control (TradeInt 2024).

Given the widespread use of polyamide kitchen utensils and the potential health risks associated with PAA migration, further research is needed to understand better exposure pathways, toxicokinetics, and long-term health effects. This study aims to contribute to this growing body of knowledge by assessing the migration behavior of PAAs from polyamide kitchen utensils and evaluating their compliance with existing regulatory frameworks.

## Experimental

### Chemicals and reagents

All Primary aromatic amine standards (Table 1) were obtained from Sigma-Aldrich (St. Louis, MO, USA). Ethanol (HPLC grade), methanol (LCMS grade), pentafluoropropionic acid (PFPA, LC-MS grade), glacial acetic acid, and ammonium acetate (HPLC grade) were obtained from Sigma-Aldrich (St. Louis, MO, USA). A Millipore Milli-Q system (Milford, MA, USA) was utilized to generate distilled water for the experiment.

### Samples

Various kitchen utensils were sampled from retailers across Turkey. The samples are categorized by product type, including whisk, bowl, spoon, cake pan, ladle, colander, crepe spatula, tong, serving spoon, spatula, and plate. Sampling was conducted by convenience from different retailers in Turkey, based on market availability at the time of purchase. Selection was designed to reflect commonly used plastic kitchen utensils available to consumers rather than to represent the entire market exhaustively. These utensils are made of different plastics such as Polyamide (PA), Polystyrene (PS), Polypropylene (PP), Polytetrafluoroethylene (PTFE) and Polyethylene (PE). A description of the analyzed kitchen utensils and their corresponding sample codes, each representing a different commercial brand, is provided in Table 2.

**Table 1.** Target compounds, their purity, carcinogenic categorization and the parameters of the mass spectrometer.

| No | CAS no | Name | IARC[1] | Purity |
|---|---|---|---|---|
| 1 | 62–53–3 | Aniline (ANL) | 2A | 99.9 |
| 2 | 101–77–9 | 4,4'-Methylenedianiline (4,4'-MDA) 4,4′ -diaminodiphenylmethane (DDPM) | 2B | 97.5 |
| 3 | 823–40–5 | 2,6-Toluenediamine (2,6-TDA) | n.c. | 99.9 |
| 4 | 95–80–7 | 2,4-Toluenediamine (2,4-TDA) 2,4-diaminotoluene (DATOL) | 2B | 99.0 |
| 5 | 119–93–7 | 3,3'-Dimethylbenzidine (3,3'-DMB) o-Tolidine | 2B | 99.0 |
| 6 | 101–80–4 | 4,4′-Diaminodiphenyl ether (4,4'-DPE) 4,4′ -oxydianiline (ODIA) | 2B | 97.5 |
| 7 | 92–67-1 | 4-aminobiphenyl (4-ABP) | 1 | 99.0 |
| 8 | 90–04–0 | *o*-anisidine (o-ASD) | 2B | 99.5 |
| 9 | 92–87–5 | Benzidine (BNZ) | 1 | 98.9 |
| 10 | 106–47-8 | 4-chloroaniline (4-CA) | 2B | 99.5 |
| 11 | 95–69-2 | 4-chloro-*o*-toluidine (4-CoT) | 2A | 99.0 |
| 12 | 95–68-1 | 2,4-Dimethylaniline (2,4-DMA) m-Xylidine | 3 | 99.5 |
| 13 | 87–62-7 | 2,6-Dimethylaniline (2,6-DMA) | 2B | 99.9 |
| 14 | 838–88–0 | 4,4-Methylenedi-o-toluidine (4,4'-MDoT) 3,3′ -dimethyl-4,4′ -diaminodiphenylmethane | 2B | 98.0 |
| 15 | 120–71-8 | 2-Methoxy-5-Methylaniline (2-M-5-MA) *p*-cresidine | 2B | 99.6 |
| 16 | 108–45-2 | m-Phenylenediamine (m-PDA) | 3 | 99.0 |
| 17 | 106–50-3 | p-Phenylenediamine (p-PDA) | 3 | 99.9 |
| 18 | 615–05–4 | 4-Methoxy-m-phenylenediamine (4-M-mPDA) | 2B | 99.5 |
| 19 | 95–53-4 | *o*-toluidine (o-T) | 1 | 99.9 |
| 20 | 137–17-7 | 2,4,5-Trimethylaniline (2,4,5-TMA) | 3 | 99.9 |

[1]Categorization of the International Agency for Research on Cancer (IARC). Group 1: carcinogenic to humans. Group 2A: probably carcinogenic to humans. Group 2B: possibly carcinogenic to humans. Group 3: not classifiable as to its carcinogenicity to humans (Trakoli 2012).
n.c. : Not categorized

**Table 2.** Description of the analyzed kitchen utensils.

| Product Type | Sample Code | Polymer Type | Product Type | Sample Code | Polymer Type |
|---|---|---|---|---|---|
| Whisk | W1 | PA | Crepe spatula | CS1 | PA |
| | W2 | PA | | CS2 | PA |
| | W3 | PA | | CS3 | PA |
| | W4 | PA | | CS4 | PA |
| | W5 | PA | | CS5 | PA |
| Bowl | B1 | PP | Tong | T1 | PA |
| | B2 | PP | | T2 | PA |
| | B3 | PE | | T3 | PA |
| | B4 | PE | | T4 | PA |
| | B5 | PP | | T5 | PA |
| Spoon | S1 | PA | Serving spoon | SS1 | PA |
| | S2 | PA | | SS2 | PA |
| | S3 | PA | | SS3 | PA |
| | S4 | PA | | SS4 | PA |
| | S5 | PA | | SS5 | PA |
| Cake pan | CP1 | PTFE | Spatula | SP1 | PA |
| | CP2 | PTFE | | SP2 | PA |
| | CP3 | PTFE | | SP3 | PA |
| | CP4 | PTFE | | SP4 | PA |
| | CP5 | PTFE | | SP5 | PA |
| Ladle | L1 | PA | Plate | P1 | PS |
| | L2 | PA | | P2 | PP |
| | L3 | PA | | P3 | PP |
| | L4 | PA | | P4 | PE |
| | L5 | PA | | P5 | PE |
| Colander | C1 | PA | | | |
| | C2 | PA | | | |
| | C3 | PA | | | |
| | C4 | PA | | | |
| | C5 | PA | | | |

PA: Polyamide, PS: Polystyrene, PP: Polypropylene, PTFE: Polytetrafluoroethylene, PE: Polyethylene.

## *Analyses of polymer-type*

The polymer types in kitchen utensils were identified using a Nicolet 6700 FTIR spectrometer (Thermo Nicolet Corp., Madison, WI) equipped with attenuated total reflectance (ATR) mode. Spectra were collected across the frequency range of 7400–350 $cm^{-1}$ with a resolution of 0.5 $cm^{-1}$. Sample spectra were analyzed by comparison with reference spectra from KnowItAll Informatics System (IR Edition v. 7.9) and HaveItAll® IR databases (Bio-Rad Laboratories, Inc.). Polyamide, Polystyrene, Polyethylene, Polypropylene and Polytetrafluoroethylene spectrums in FTIR are provided in Figures S4, S5, S6, S7 and S8.

## *Migration test and sample preparation*

Migration tests were conducted in accordance with the European Regulation (EU) No. 10/2011 on plastic materials and articles intended to come into contact with food (Commission Regulation (EU) 2020). Aqueous food simulant, 3% (w/v) acetic acid (Simulant B), was used as specified by the regulation. Each kitchen utensil was individually placed into a beaker and filled with a predetermined volume of the simulant. The beakers were then covered with aluminum foil and placed in a preheated oven under controlled conditions. For primary aromatic amine experiments, worst-case testing conditions were selected in accordance with EN 13,130–1:2004 (CEN 2004). The migration tests were conducted at two specific temperature and time conditions: 70°C ±2°C for 2 h and 100°C ±3°C for 2 h (Commission Regulation (EU) 2020). After exposure, the food simulant was carefully transferred to vials for subsequent analysis. To evaluate repeated use, second and third migration tests were performed, denoted as the 2$^{nd}$ and 3$^{rd}$ migrations, respectively, and each migration test was performed in triplicate.

## *LC-MS/MS analyses*

Each sample was analyzed using an Agilent 1260 liquid chromatography system coupled with an Agilent 6460 triple quadrupole mass spectrometer (Agilent Technologies, USA). Chromatographic separation was performed on a Zorbax SB-C3 column (2.1 mm × 150 mm, 5 µm) at 35°C. The mobile phase consisted of solution A (4.7 mM pentafluoropropionic acid [PFPA] in methanol) and solution B (4.7 mM PFPA in Milli-Q water). The following gradient elution program was applied:

- **0-3 min**: 20% A at 0.2 mL/min,
- **3-7.5 min**: linear gradient from 20% to 80% A, with flow increasing from 0.2 to 0.5 mL/min,
- **7.5-8 min**: 80% A at 0.5 mL/min,
- **8-11 min**: 5% A at 0.5 mL/min,
- **11-15 min**: 5% A at 0.2 mL/min.

The mass spectrometer was equipped with an Agilent Jet Stream electrospray ionization (ESI) source operating in positive ion mode, and the mass spectrometer parameters are given in Table 1. The optimized source parameters were as follows: source temperature, 130°C; capillary voltage, 4 kV; nebulizer gas pressure, 45 psi; and dry gas flow rate, 11 L/min. All conditions complied with the EU 10/2011 regulation (Commission Regulation (EU) 2020). The calibration curve for aniline and the chromatograms of aniline and 4,4′-MDA in the samples are presented in Figures S2, S1, and S3, respectively. Figure S9 compares the retention times of the external standards.

### *Method validation*

The method was validated according to Toptancı et al. (2022). The LC-MS/MS method used for analyzing primary aromatic amines was validated for key quality parameters, including linearity, limit of detection (LOD), limit of quantification (LOQ), precision, and accuracy. The LOD was defined as the lowest concentration of a substance reliably detectable, while the LOQ represented the lowest concentration quantifiable with acceptable accuracy. Blank samples were analyzed using the method, and standard deviations were calculated from 10 replicate measurements. The LOD and LOQ were determined as three and ten times the standard deviation, respectively. The LOD values ranged from 0.25 to 0.34 μg/kg, and the LOQ values ranged from 1.02 to 1.15 μg/kg.

Calibration curves were constructed using seven concentration levels for each primary aromatic amine: blank, 1, 2, 5, 10, 25, and 50 μg/kg, prepared in food simulant B (3%, w/v, acetic acid). The method exhibited excellent linearity across the concentration range, with correlation coefficients ($R^2$) exceeding 0.995 for all analytes.

Method recovery was assessed through spiking experiments at a concentration level of 2 μg/kg, using food simulant B as the blank matrix. The average recovery values ranged from 83% to 114%, with relative standard deviation (RSD) values below 20% for all tested PAAs. Within-laboratory reproducibility (intermediate precision) ranged from 3% to 8%. Table S1 shows the validation parameters of the tested compounds.

## Results and discussion

The FTIR spectra confirmed that the samples analyzed were indeed polymeric. The amide-related absorptions of Polyamide (PA) at approximately 3300 $cm^{-1}$ (N – H stretching), 1630 $cm^{-1}$ (amide I, C = O stretching), and 1535 $cm^{-1}$ (amide II, N – H bending in combination with C – N stretching) indicate its presence. Polypropylene (PP), on the other hand, has very prominent $CH_2$/$CH_3$ stretching bands between 2950–2850 $cm^{-1}$ and also features deformation peaks at 1455 and 1375 $cm^{-1}$. Polyethylene (PE) shows the typical methylene stretching vibrations found at 2915 and 2848 $cm^{-1}$ along with bending modes located at 1472 and 730 $cm^{-1}$. Polystyrene (PS) was known by aromatic C = C stretching found at both 1601 and 1493 $cm^{-1}$, plus out-of-plane ring deformation around 700 $cm^{-1}$. PTFE spectra revealed the typical C-F bond stretching vibrations within the 1200–1140 $cm^{-1}$ range and the absence of any CH-related signals, thus confirming that this sample was a fluoro polymer.

The levels of primary aromatic amines (PAAs) were determined in 55 kitchen utensils marketed in Turkey. PAAs were not detected in 25 of the samples. As shown in Table 3, at least one PAA was detected and quantified in the remaining 30 samples. Following the first migration test, aniline was detected at concentrations of 0.050–0.076 mg/kg in samples CS5 and SS3, respectively. After the third migration,

**Table 3.** Concentration of aniline, 4,4'-MDA, 2,6-TDA, 2,4-TDA, o-T, 3,3'-DMB and Total PAA (mg/kg) in detected samples depending on migration cycles (1, first migration; 2, second migration; 3, third migration).

| | Sample code | Aniline $1^{st}$ migration $2^{nd}$ migration $3^{rd}$ migration | 4,4'-MDA $1^{st}$ migration $2^{nd}$ migration $3^{rd}$ migration | 2,6-TDA $1^{st}$ migration $2^{nd}$ migration $3^{rd}$ migration | 2,4-TDA $1^{st}$ migration $2^{nd}$ migration $3^{rd}$ migration | o-T $1^{st}$ migration $2^{nd}$ migration $3^{rd}$ migration | 3,3'-DMB $1^{st}$ migration $2^{nd}$ migration $3^{rd}$ migration | Total PAA $1^{st}$ migration $2^{nd}$ migration $3^{rd}$ migration |
|---|---|---|---|---|---|---|---|---|
| 1 | W3 | 0.043 ± 0.005 | 0.012 ± 0.001 | nd | nd | 0.005 ± 0.001 | nd | 0.06 ± 0.006 |
| | | 0.035 ± 0.004 | 0.006 ± 0.001 | nd | nd | nd | nd | 0.041 ± 0.005 |
| | | 0.027 ± 0.004 | nd | nd | nd | nd | nd | 0.027 ± 0.004 |
| 2 | W4 | 0.021 ± 0.004 | nd | nd | nd | nd | nd | 0.021 ± 0.003 |
| | | 0.013 ± 0.003 | nd | nd | nd | nd | nd | 0.013 ± 0.003 |
| | | 0.009 ± 0.002 | nd | nd | nd | nd | nd | 0.009 ± 0.002 |
| 3 | W5 | 0.009 ± 0.003 | nd | nd | nd | nd | nd | 0.014 ± 0.002 |
| | | 0.003 ± 0.001 | nd | nd | nd | nd | nd | 0.003 ± 0.001 |
| | | nd | nd | nd | nd | nd | nd | nd |
| 4 | S1 | 0.006 ± 0.001 | nd | nd | 0.005 ± 0.001 | nd | 0.008 ± 0.001 | 0.019 ± 0.001 |
| | | nd | nd | nd | nd | nd | nd | nd |
| | | nd | nd | nd | nd | nd | nd | nd |
| 5 | S2 | 0.014 ± 0.002 | nd | nd | nd | nd | nd | 0.014 ± 0.002 |
| | | 0.008 ± 0.002 | nd | nd | nd | nd | nd | 0.008 ± 0.002 |
| | | 0.003 ± 0.001 | nd | nd | nd | nd | nd | 0.003 ± 0.001 |
| 6 | S3 | 0.009 ± 0.001 | nd | nd | nd | nd | nd | 0.009 ± 0.001 |
| | | 0.004 ± 0.001 | nd | nd | nd | nd | nd | 0.004 ± 0.001 |
| | | nd | nd | nd | nd | nd | nd | nd |
| 7 | CP1 | 0.014 ± 0.002 | nd | nd | nd | nd | nd | 0.014 ± 0.002 |
| | | 0.008 ± 0.002 | nd | nd | nd | nd | nd | 0.006 ± 0.002 |
| | | nd | nd | nd | nd | nd | nd | nd |
| 8 | CP5 | 0.01 ± 0.001 | nd | nd | nd | nd | nd | 0.01 ± 0.001 |
| | | 0.006 ± 0.002 | nd | nd | nd | nd | nd | 0.006 ± 0.002 |
| | | nd | nd | nd | nd | nd | nd | nd |
| 9 | L2 | 0.01 ± 0.002 | nd | nd | nd | nd | nd | 0.01 ± 0.002 |
| | | 0.007 ± 0.001 | nd | nd | nd | nd | nd | 0.007 ± 0.001 |
| | | nd | nd | nd | nd | nd | nd | nd |
| 10 | L3 | 0.009 ± 0.001 | 0.004 ± 0.001 | nd | nd | nd | nd | 0.013 ± 0.001 |
| | | 0.005 ± 0.001 | nd | nd | nd | nd | nd | 0.005 ± 0.001 |
| | | nd | nd | nd | nd | nd | nd | nd |
| 11 | L5 | nd | 0.011 ± 0.002 | nd | nd | nd | nd | 0.011 ± 0.002 |
| | | nd | 0.006 ± 0.001 | nd | nd | nd | nd | 0.006 ± 0.001 |
| | | nd | nd | nd | nd | nd | nd | nd |
| 12 | C2 | 0.015 ± 0.002 | 0.005 ± 0.001 | nd | nd | nd | nd | 0.02 ± 0.001 |
| | | 0.009 ± 0.001 | nd | nd | nd | nd | nd | 0.009 ± 0.001 |
| | | 0.004 ± 0.001 | nd | nd | nd | nd | nd | 0.004 ± 0.001 |
| 13 | C3 | nd | nd | nd | nd | nd | nd | nd |
| | | nd | nd | nd | nd | nd | nd | nd |
| | | nd | nd | nd | nd | nd | nd | nd |
| 14 | C4 | 0.027 ± 0.004 | nd | nd | nd | 0.008 ± 0.002 | nd | 0.035 ± 0.004 |
| | | 0.018 ± 0.002 | nd | nd | nd | 0.003 ± 0.001 | nd | 0.021 ± 0.002 |
| | | 0.011 ± 0.002 | nd | nd | nd | nd | nd | 0.011 ± 0.002 |
| 15 | CS1 | 0.015 ± 0.002 | 0.004 ± 0.001 | nd | nd | nd | nd | 0.019 ± 0.002 |
| | | 0.008 ± 0.002 | nd | nd | nd | nd | nd | 0.008 ± 0.002 |
| | | 0.003 ± 0.001 | nd | nd | nd | nd | nd | 0.003 ± 0.001 |
| 16 | CS3 | 0.052 ± 0.007 | nd | nd | nd | nd | nd | 0.052 ± 0.007 |
| | | 0.046 ± 0.005 | nd | nd | nd | nd | nd | 0.046 ± 0.005 |
| | | 0.038 ± 0.004 | nd | nd | nd | nd | nd | 0.038 ± 0.004 |
| 17 | CS4 | 0.009 ± 0.001 | nd | nd | nd | nd | nd | 0.009 ± 0.001 |
| | | 0.005 ± 0.001 | nd | nd | nd | nd | nd | 0.005 ± 0.001 |
| | | nd | nd | nd | nd | nd | nd | nd |
| 18 | CS5 | 0.005 ± 0.001 | nd | nd | nd | nd | nd | 0.005 ± 0.001 |
| | | nd | nd | nd | nd | nd | nd | nd |
| | | nd | nd | nd | nd | nd | nd | nd |
| 19 | T1 | 0.036 ± 0.005 | 0.008 ± 0.002 | nd | nd | nd | nd | 0.044 ± 0.004 |
| | | 0.025 ± 0.002 | nd | nd | nd | nd | nd | 0.025 ± 0.002 |
| | | 0.011 ± 0.001 | nd | nd | nd | nd | nd | 0.011 ± 0.001 |
| 20 | T2 | 0.022 ± 0.003 | nd | nd | nd | nd | nd | 0.022 ± 0.003 |
| | | 0.016 ± 0.002 | nd | nd | nd | nd | nd | 0.016 ± 0.002 |
| | | 0.009 ± 0.001 | nd | nd | nd | nd | nd | 0.009 ± 0.001 |
| 21 | T3 | nd | nd | nd | nd | 0.005 ± 0.001 | nd | 0.005 ± 0.001 |
| | | nd | nd | nd | nd | nd | nd | nd |
| | | nd | nd | nd | nd | nd | nd | nd |
| 22 | T4 | 0.006 ± 0.001 | nd | nd | nd | nd | nd | 0.006 ± 0.001 |
| | | nd | nd | nd | nd | nd | nd | nd |
| | | nd | nd | nd | nd | nd | nd | nd |

(*Continued*)

**Table 3.** (Continued).

| | Sample code | Aniline 1st migration 2nd migration 3rd migration | 4,4'-MDA 1st migration 2nd migration 3rd migration | 2,6-TDA 1st migration 2nd migration 3rd migration | 2,4-TDA 1st migration 2nd migration 3rd migration | o-T 1st migration 2nd migration 3rd migration | 3,3'-DMB 1st migration 2nd migration 3rd migration | Total PAA 1st migration 2nd migration 3rd migration |
|---|---|---|---|---|---|---|---|---|
| 23 | T5 | 0.008 ± 0.002 | nd | nd | nd | nd | nd | 0.008 ± 0.002 |
| | | 0.004 ± 0.001 | nd | nd | nd | nd | nd | 0.004 ± 0.001 |
| | | nd | nd | nd | nd | nd | nd | nd |
| 24 | SS1 | 0.011 ± 0.001 | nd | nd | nd | nd | nd | 0.011 ± 0.001 |
| | | 0.008 ± 0.002 | nd | nd | nd | nd | nd | 0.008 ± 0.002 |
| | | nd | nd | nd | nd | nd | nd | nd |
| 25 | SS3 | 0.076 ± 0.01 | nd | nd | nd | nd | nd | 0.076 ± 0.01 |
| | | 0.065 ± 0.009 | nd | nd | nd | nd | nd | 0.065 ± 0.09 |
| | | 0.057 ± 0.007 | nd | nd | nd | nd | nd | 0.057 ± 0.07 |
| 26 | SS5 | 0.007 ± 0.001 | 0.009 ± 0.002 | nd | nd | nd | nd | 0.016 ± 0.001 |
| | | 0.002 ± 0.001 | 0.005 ± 0.001 | nd | nd | nd | nd | 0.007 ± 0.001 |
| | | nd | nd | nd | nd | nd | nd | nd |
| 27 | SP1 | 0.034 ± 0.005 | 0.005 ± 0.001 | nd | nd | nd | 0.005 ± 0.001 | 0.044 ± 0.004 |
| | | 0.026 ± 0.004 | nd | nd | nd | nd | 0.003 ± 0.001 | 0.029 ± 0.004 |
| | | 0.012 ± 0.001 | nd | nd | nd | nd | nd | 0.012 ± 0.001 |
| 28 | SP2 | 0.01 ± 0.002 | 0.007 ± 0.001 | nd | nd | nd | 0.004 ± 0.001 | 0.021 ± 0.001 |
| | | 0.005 ± 0.001 | 0.004 ± 0.001 | nd | nd | nd | nd | 0.009 ± 0.001 |
| | | 0.003 ± 0.001 | nd | nd | nd | nd | nd | 0.003 ± 0.001 |
| 29 | SP3 | 0.017 ± 0.003 | nd | 0.004 ± 0.001 | 0.003 ± 0.001 | nd | nd | 0.024 ± 0.002 |
| | | 0.011 ± 0.001 | nd | nd | nd | nd | nd | 0.011 ± 0.001 |
| | | 0.007 ± 0.001 | nd | nd | nd | nd | nd | 0.07 ± 0.001 |
| 30 | SP5 | 0.006 ± 0.001 | nd | nd | nd | nd | nd | 0.006 ± 0.001 |
| | | 0.002 ± 0.001 | nd | nd | nd | nd | nd | 0.002 ± 0.001 |
| | | nd | nd | nd | nd | nd | nd | nd |

4,4'-MDA:4,4'-Methylenedianiline, 2,6-TDA:2,6-Toluenediamine, 2,4-TDA:2,4-Toluenediamine, o-T: *o*-Toluidine, 3,3'-DMB:3,3'-Dimethylbenzidine, PAA: Primary aromatic amine, nd: not detected.

aniline was not detected in 17 samples; however, the highest concentration observed was 0.057 mg/kg in sample SS3. The highest concentration of 4,4′-methylenedianiline (0.012 mg/kg) was detected in sample W3 after the first migration, whereas this compound was not detected in any sample after the third migration. 2,6-Toluenediamine and 2,4-toluenediamine were detected only in samples S1 and SP3 following the first migration. o-Toluidine was detected after the first migration at concentrations of 0.050, 0.080, and 0.050 mg/kg in samples W3, C4, and T3, respectively. Additionally, 3,3′-dimethylbenzidine was detected after the first migration in samples SP1 (0.050 mg/kg), SP2 (0.040 mg/kg), and S1 (0.008 mg/kg). Overall, the highest total PAA concentration was observed in sample SS3 (0.057 mg/kg), as summarized in Table 3. The results were similar to those of Trier and Granby (2015) and Perez et al. (2021), who examined that Methylenedianiline and aniline were the PAAs detected in kitchen utensils. Similar to previous studies conducted in Turkey and several EU member states, aniline was the most frequently detected PAA and the dominant migrant, particularly in polyamide-based utensils, reflecting its widespread use as a residual or degradation product of aromatic isocyanates. Reported concentrations in EU and international surveys are typically low and sporadic, often below regulatory limits, but occasional exceedances have been documented, especially after initial migration tests.

The results of the migration tests for aniline are presented in Figure 1. After the first migration, aniline concentrations exceeded the limit of quantification (LOQ) in 27 samples, ranging from 0.005 mg/kg to 0.076 mg/kg. However, following the third migration, this number decreased to 13 samples, indicating a reduction in detectable aniline over successive extractions. Aniline is a toxic compound that poses significant health risks through vapor inhalation, ingestion, or dermal absorption. The International Agency for Research on Cancer (IARC 2021) has classified aniline as Group 2A-probably carcinogenic to humans due to its strong association with bladder cancer.

The presence and concentration of aniline in the detected samples studied in this work were similar to those reported by other authors (Sanchis et al. 2015; Trier and Granby 2015; Perez et al. 2021). Trier and Granby (2015) found that the concentration of aniline in 25 black nylon (polyamide) kitchen utensils from Norwegian markets ranged from 0.6 to 2.3 µg/kg. Sanchis et al. (2015) also observed that the predominant PAA migrant concentration ranged from 2.5 to 283 µg/kg across 10 kitchen utensils from different retailers in Spain. Aniline was detected in five of 36 kitchen utensils at levels ranging from 11 to 300 µg/kg by Perez et al. (2021). The sustained release of aniline across successive migration tests suggests diffusion-controlled

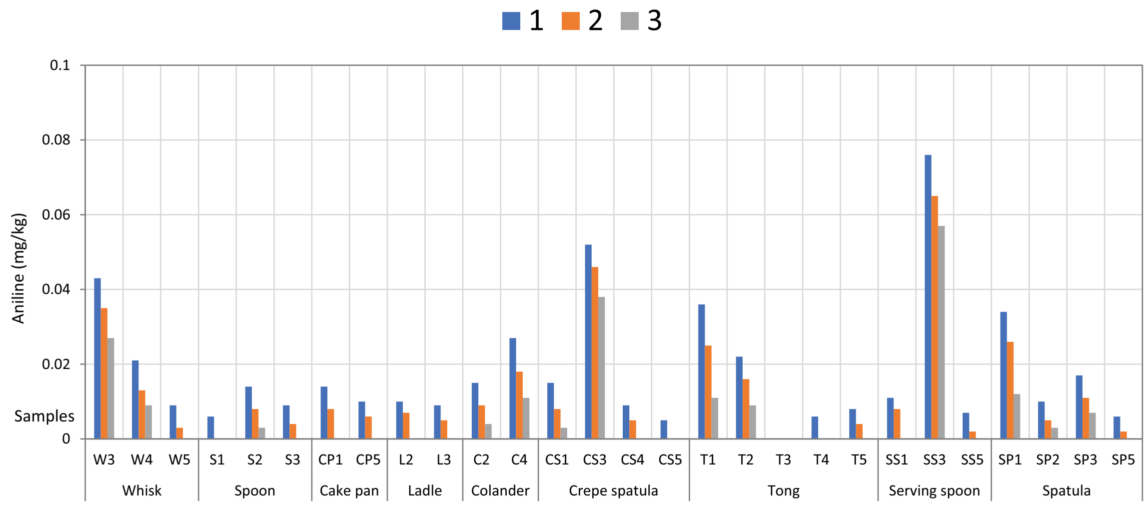


**Figure 1.** The concentration of aniline (mg/kg) in detected samples depends on the sample type and migration cycles (1, first migration; 2, second migration; 3, third migration).

migration from within the polymer matrix rather than surface contamination (Brede and Skjevrak 2004). This behavior is likely linked to residual monomers or degradation products retained in the polymer, with polar functional groups in materials such as polyamides and polyurethanes further slowing diffusion through intermolecular interactions. Manufacturing factors, including incomplete polymerization, insufficient curing, or the use of recycled materials, may contribute to the retention and progressive migration of aromatic amines (Mutsuga et al. 2010; Gupta et al. 2024).

4,4'-Methylenedianiline was detected above LOQ in 10 samples, as shown in Figure 2, with values ranging from 0.004 to 0.012 mg/kg, CS1 and W3, respectively, in the first migration test. 4,4'-Methylenedianiline studied in this work was previously reported as the main PAAs in kitchen utensils by other authors (Sanchis et al. 2015; Trier and Granby 2015; Perez et al. 2019, 2021). Perez et al. (2021) found 4,4'-methylenedianiline as the predominant PAA detected in seven kitchen utensils, with values ranging from 25 to 9793 μg/kg in the third migration test. A similar study by Perez et al. (2019) found that 4,4'-methylenedianiline was the predominant PPA, and the concentration of this PAA was determined in 11 kitchen utensils, ranging between 2.6 and 10,949 μg/kg in the third migration test. Trier and Granby (2015)

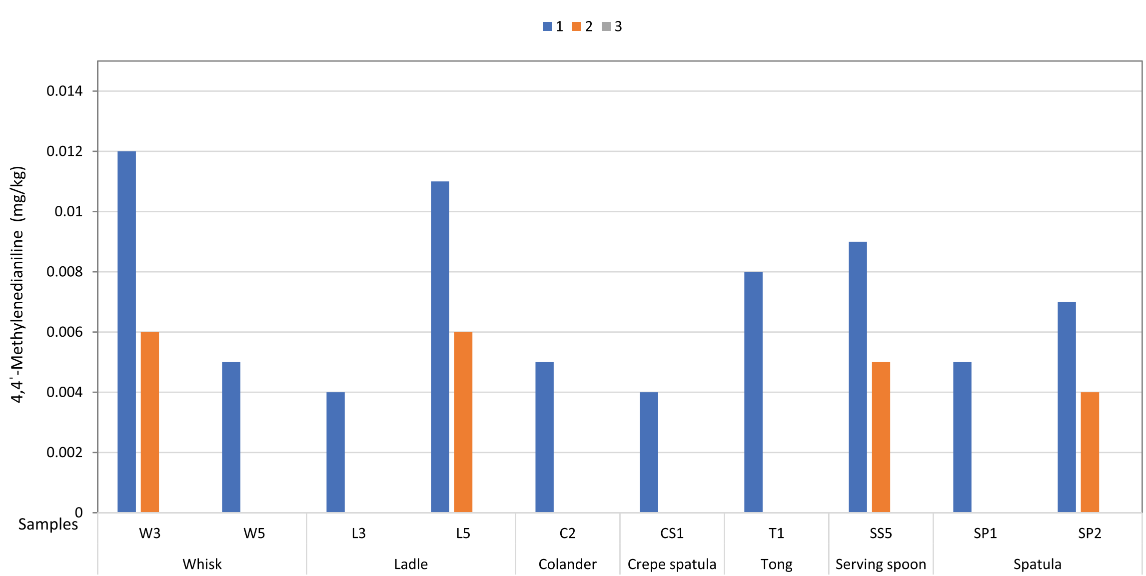


**Figure 2.** The concentration of 4,4'-methylenedianiline (mg/kg) in detected samples depends on the sample type and migration cycles (1, first migration; 2, second migration; 3, third migration).

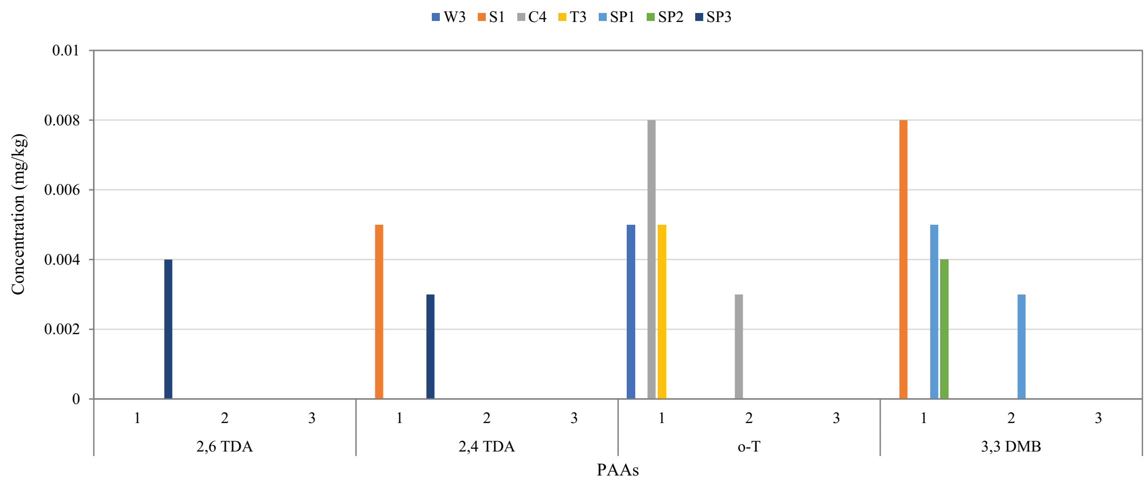


**Figure 3.** The concentration of 2,6-TDA, 2,4-TDA, *o*-T and 3,3'-DMB (mg/kg) in detected samples, depending on the sample type and migration cycles (1, first migration; 2, second migration; 3, third migration).

found that the 4,4′-methylenedianiline detected in 11 kitchen utensils from Norwegian markets ranged from 0.6 to 14 µg/kg. Sanchis et al. (2015) found that the concentration of 4,4′-methylenedianiline in six kitchen utensils ranged between 2 and 19.715 µg/kg.

After the first extraction, o-toluidine and 3,3'-dimethylbenzidine were detected above LOQ in three samples (Figure 3). However, 2,6-toluenediamine and 2,4-toluenediamine were detected in one and two samples in the first migration test, with concentrations of 0.004 mg/kg and 0.003, 0.005 mg/kg, respectively. After the third migration test, these PAAs were not detected or were below their LOQ in all analyzed samples. 3,3'-Dimethylbenzidine and 2,4-toluenediamine are classified as possibly carcinogenic to humans, while o-toluidine is classified as carcinogenic to humans, according to IARC (IARC 2021). *O*-Toluidine, 3,3 '-dimethylbenzidine, 2,6-toluenediamine and 2,4-toluenediamine were also detected in this work and were also reported in the literature according to other authors (Sanchis et al. 2015; Perez et al. 2021).

Generally, the first-to-second and second-to-third migration values decreased. The same phenomenon was observed in the Perez et al. (2019) study, and Perez et al. (2021) studied PAAs in cooking utensils and kitchenware.

The third migration is shown in Figure 4, the total amount of PAAs constituents' aniline content, because other detected PAAs, including 4,4'-methylenedianiline, *o*-toluidine, 3,3'-dimethylbenzidine, 2,6-toluenediamine

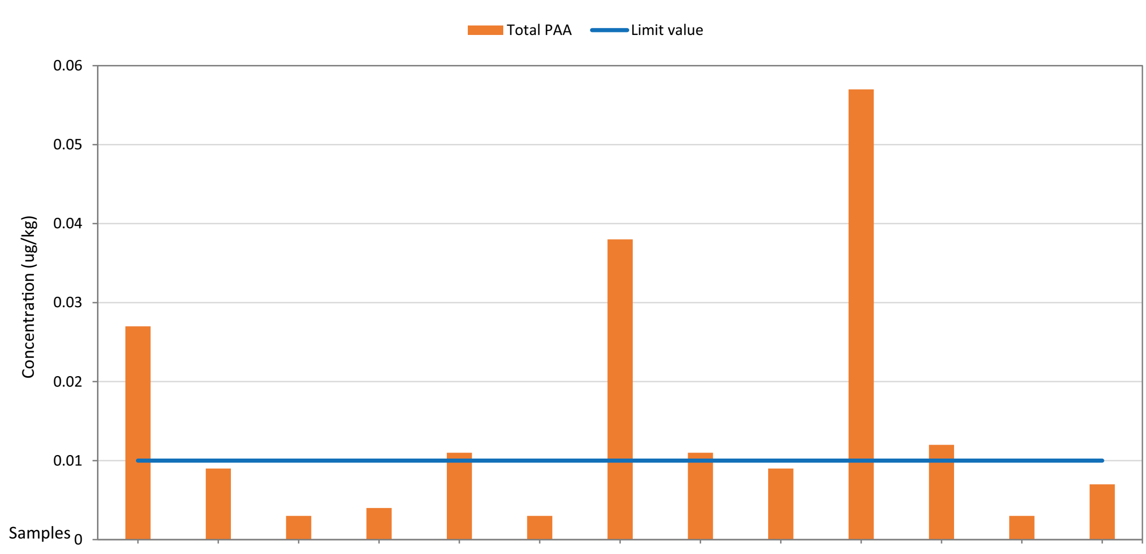


**Figure 4.** The total content of PAAs present in kitchen utensils.

and 2,4-toluenediamine were detected at levels below their LOQ values, so they did not contribute to the total level of PAAs.

Overall, the migration results indicate that consumer exposure to primary aromatic amines from polyamide-based kitchen utensils is greatest during initial use, when the highest concentrations are consistently observed. Although PAA levels generally declined over successive migrations, the detection of carcinogenic compounds such as aniline and o-toluidine, classified by IARC as Group 2A and Group 1, respectively, highlights a potential exposure concern, particularly under worst-case conditions. Most measured concentrations were low and broadly comparable with those reported in EU and international surveys; however, detections near regulatory thresholds during the first migration tests underscore the importance of a conservative compliance assessment. These findings support the continued application of stringent EU limits for PAAs in food-contact materials and emphasize the need for routine market surveillance, especially for polyamide utensils, where diffusion-controlled migration from residual monomers or degradation products may occur.

## Conclusions

This study provides a targeted assessment of primary aromatic amine (PAA) migration from kitchen utensils marketed in Turkey, offering new insight into the occurrence and regulatory relevance of these contaminants in food-contact materials. These findings suggest that sporadic but consequential contamination may arise from specific material formulations or manufacturing practices, reinforcing the importance of expanded surveillance across product types, polymer technologies, and supply chains. From a risk communication perspective, these findings underscore the importance of clear guidance to consumers on appropriate use conditions (e.g. temperature and contact time) and reinforce the need for targeted regulatory monitoring of high-risk product categories to ensure continued compliance and consumer confidence. Future work should integrate longitudinal monitoring with refined exposure and risk characterization frameworks that reflect realistic use scenarios, enabling a more robust translation of analytical data into public health decision-making. Such work would support the development of more effective regulatory measures and manufacturing practices, ultimately strengthening consumer protection and ensuring compliance with global food-contact safety standards.

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Sezer Kıralan: conceptualization, methodology, data curation, and writing the original draft. İsra TOPTANCI: methodology and data curation. Mohamed Fawzy Ramadan: Data curation and writing of the original draft.

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