Microplastic Debris in Palm Cooking Oil: A Call for Research


1Plant Production and Biotechnology – PT Smart Tbk., Bogor 16810, West Java, Indonesia
2University of Agriculture Peshawar, Pakistan 25130, Khyber Pakhtunkhwa, Pakistan
3Universitas Islam Madura, Pamekasan 69317, Madura, East Java, Indonesia
4University of Muhammadiyah Malang, Malang 65144, East Java, Indonesia
5The State Islamic University of Maulana Malik Ibrahim, Malang 65144, East Java, Indonesia
6Research Center for Food Technology and Processing (BRIN), Special Region of Yogyakarta 55861
7Merdeka University of Madian, Madian 63133, East Java, Indonesia
8Central Research and Diagnostic Laboratory - Satwa Sehat Indonesia, Malang 65146, Indonesia
9University of Latvia, Riga LV-1004, Latvia
10University of Brawijaya, Malang 65145, East Java, Indonesia
11IPB University, Bogor 16680, West Java, Indonesia

Abstract. Microplastic (MPs) contamination investigations have been carried out on 16 cooking oil brands, especially palm cooking oil. MPs analysis used modified fenton oxidative degradation and identification through light optical microscopy. The investigation results presented that all cooking oil brands were dirtied with MPs. The most minor abundance of MPs (0.07 ± 0.09) mL–1 particle is in the TL brand, a premium cooking oil, that matches imported canola oil (Ma. brand). Bulk cooking oil is contaminated with the highest MPs (0.37 ± 0.05) mL–1 particle, but the contamination can be reduced with packaging, as shown in the Minyakkita brand (0.28 ± 0.05) mL–1 particle. Red palm oil has contamination i.e., (0.23 ± 0.05) mL–1 to (0.50 ± 0.05) mL–1 particle. Investigations at three street vendors of fried food showed that the snacks were contaminated with MPs. Black fiber particles dominate the pollution in cooking oil and fried snacks. It’s suspected that MP pollution has occurred during the CPO process. Considering MPs' harmful impacts on human health, comprehensive research should be conducted to minimize MP pollution in palm cooking oil. This action must be carried out as a campaign for healthy Indonesian palm oil cooking.

Keywords: Edible oil, Elaeis guineensis Jacq., harmful, hidden danger

* Corresponding author: damatumm@gmail.com

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).
1 Introduction

Cooking oil is one of the nine basic products (sembako) needed by the Indonesian people as stipulated in the Decree of the Minister of Industry and Trade – Republic of Indonesia, No. 115/MPP/Kep/2/1998 on 27 February 1998 [1–3]. Presidential Regulation (Perpres) No. 71 of 2015 (Article 2, paragraph 6), confirms that cooking oil is a type of basic necessity item [4]. Kasryno [5] and Agastya et al. [6] stated that cooking oil is part of national food security and has an influence on inflation data in Indonesia [7, 8].

Cooking oil is considered an important ingredient because Indonesian people have a culture of consuming a fried foods [9, 10]. Cooking oil can improve the culinary taste to make it savorier and crunchier as well as being used as shortening [11–13]. Cooking oil is also important as a food ingredient in providing energy and fat sources [3, 4], as well as improving nutrition [14]. Researchers [15–17] stated 1 g of edible oil can produce 9 kcal, while 1 g of carbohydrates and protein only produces 4 kcal.

Cooking oil, primarily derived from palm oil, dominates the market in Indonesia, constituting 90 % of the total usage, surpassing other cooking oil, like coconut and corn oil [18, 3]. Over the years, per capita use of cooking oil in Indonesia has surged significantly, increased from approximately 5.2 kg capita⁻¹ in 1980 to 10.7 kg capita⁻¹ in 2000, and persisting in its upward trajectory to reach 19.7 kg capita⁻¹ in 2020 [19]. According to data from the USDA [20], Indonesia's palm cooking oil consumption in 2020/2021 peaked at 15 275 t, surpassing that of India and China [20–25, 17], making Indonesia be the world’s highest consumer of cooking oil. Susenas 2022 (Survei Sosial Ekonomi Nasional - National Socioeconomic Survey) [26] reveals that 90.27 % of households actively consume cooking oil, with an average monthly expenditure per household of IDR 71 915, derived from an average per capita expenditure of IDR 1 327 782.

In line with the classification of essential goods, the Indonesian government oversees their accessibility. Cooking oil is categorized into five types based on its intended use: (i) bulk cooking oil (minyak goreng curah rakyat – MGCR), (ii) simple packaged cooking oil, (iii) premium packaged cooking oil, (iv) bulk cooking oil for industrial use, and (v) olein for other industrial purposes [27]. These five types will be increased in 2024 by (vi) red palm olein (minyak makan merah – M3), with the inauguration of the factory in Pagar Merbau II village, Deli Serdang Regency, North Sumatra by President Jokowi on March 14, 2024 [28, 29].

The availability of cooking oil is governed by regulations on the Domestic Market Obligation (DMO) and Domestic Price Obligation (DPO) [30, 31]. So far, the Ministry of Trade has implemented a CPO export ratio in the DMO policy of 1:4 since May 2023. This means that producers can export a volume four times the DMO distribution volume. Apart from that, the government also provides a multiplier incentive for DMOs in the form of two times oil for “pillow packaging” and 2.25 times for packaging other than “pillows.” [32, 33].

The government ensures the quality of cooking oil traded domestically and internationally. The Ministry of Industry – Republic of Indonesia and the National Standards Agency (Badan Standardisasi Nasional – BSN) introduced the SNI 7709:2012 policy, later revised to SNI 7709:2019. Food categories are determined by National Food and Drug Agency (Badan Pengawas Obat dan Makanan - BPOM) with Decree No. 34 of 2019. Additionally, the Ministry of Trade implemented a mandatory palm cooking oil packaging policy through Minister of Trade Regulation 9/2016, complemented by decrees from the National Food and Drug Agency (BPOM) regarding distribution permits and supervision of palm cooking oil [33, 17]. Especially for M3, the standard is using SNI 9098:2022. However, SNI 7709:2019 and BPOM No. 34 of 2019 lack a threshold for microplastic (MPs) contamination.
MPs pose a risk of contaminating human-consumed food and beverages [34, 35], especially with the escalating utilization of plastic, notably single-use packaging and plastic waste, heightening the likelihood of MPs accumulating in the food chain [36]. They infiltrate marine animals [37], land fauna, and flora, thereby exposing humans to MPs upon consumption [38], leading to potential health repercussions. Early studies have associated MPs exposure with health risks like inflammation, hormonal disruption, and potential carcinogenic effects [39–43].

Guo et al. [44] documented MPs ranging from \((1.34 \times 10^5\) to \(5.80 \times 10^5\) \(L^{-1}\)) particles in four cooking oil types (olive, canola, sunflower, and coconut oil), with over 50% identified as MPs (5 mm to 1 \(\mu\)m) and over 80% smaller than 10 \(\mu\)m. Battaglini et al. [45] corroborated these findings, revealing contamination of vegetable oils from Spain and Italy, containing extra virgin olive oil, olive oil, sunflower oil, and oil mixed blends various seeds, with MPs measuring \(1 \pm 350 \text{ MPs L}^{-1}\). The detected MPs predominantly comprised fragments (81.2%), with particle sizes \(< 100 \text{ \mu m} (77.5\%)\), primarily comprised of polyethylene (50.3%) and polypropylene (28.7%).

Earlier studies detected MPs in widely distributed potato chips in Indonesia, potentially linked to contaminated cooking oil. While research on MPs contamination in palm cooking oil is lacking, but many reports indicate street food vendors incorporating plastic into cooking oil during frying to prolong snack shelf life, enhance crispiness, and improve appearance [46–51]. Google search results from March 1, 2024, yielded 294 000 entries related to unethical practices of fried street vendors, prioritizing profits over public health.

Sari et al. [46] conducted an analysis on ten samples of used cooking oil from street vendor in the Jati area, Padang city, West Sumatra province. GC-MS analysis revealed isopropyl compounds from polyethylene and polypropylene plastic in nine out of ten samples. Ryosa et al. [47] corroborated Sari et al.'s research, finding plastic derivatives including benzene (phthalates), acrylic, and cyclopentene in three out of five samples. Phthalates are hydrophobic compounds added to plastic materials to increase their flexibility [52]. Lopez-Carrillo et al. [53] showed a positive correlation of phthalates with individual breast cancer and reproductive faults occurrence.

Considering palm cooking oil's essential role for Indonesians and its prominence in exports, addressing microplastic pollution in Crude Palm Oil, particularly in cooking oil, is crucial [54, 55, 1–7]. It has become a focal point in negative campaigns, emphasizing the necessity for assessing microplastic contamination in cooking oil to ensure food safety [56, 57].

2 Material and method

2.1 Sampling

Palm cooking oil and fried street snacks were collected randomly in the city of Malang, East Java, Indonesia. Locations for sampling cooking oil was Sarana Tidar Indah (coordinate S 7°57'46.7964" and E 112°36'25.6824"), traditional market in Sarana Tidar Indah (S 7°57'38.8764" and E 112°36'4.9896"), Mergan’s traditional market (S 7°58'58.2384" and E 12°36'52.5384"), Oro-Oro Dowo’s traditional market (S7°58'7.302" and E 112°37'41.448"), two canteen in Faculty of Science and Technology, State Islamic University of Maulana Malik Ibrahim, Malang (S 7°57'2.3328" and E 112°36'24.5592").

Samples of fried snacks was taken at three locations, including A) at the Sarana Tidar Indah market (S 7°57'38.8764" and E 112°36'4.9896"), B) at a vendor fried snack, near the Brawijaya University campus, State Islamic University of Maulana Malik Ibrahim, and Malang National Institute of Technology (S 7°57'14.6376" and E 112°36'37.8288"), and
C) at a vendor fried snack near the Malang Institute of Agriculture campus (S 7°56’33.4392" and E 112°37’17.4216”).

The selection of cooking oil samples was based on two sources, namely i) "top brand award 2023 and 2024" including Bi., Fa., Sa., So., and Tl. brand [58], and ii) statement by the Executive Director of Indonesian Vegetable Oil Industry Association (Gabungan Industri Minyak Nabati Indonesia - GIMNI) that there are five large companies out of 75 cooking oil manufacturer that dominate the Indonesia market, namely PT Indofood Sukses Makmur Tbk, Wilmar Group, PT Sinarmas Agribusiness and Food, PT Bina Karya Prima, and Musim Mas Group [59, 60].

As a complement to the premium packaged cooking oil samples mentioned above, bulk cooking oil (minyak goreng curah rakyat – MGCR) samples were purchased from two traditional markets (Mergan and Oro-Oro Dowo), Minyakkita brand—packaged bulk cooking oil, a product of a small company in Sidoarjo, East Java (S 7° 25’53.1372" and E 112°44’10.6944”) purchased at the Sarana Tidar Indah traditional market, and cooking oil produced by a “small factory” with the Ao brand (production from a company in Malang Regency – S 8°10’28.56° and E 112°38’16.4616”). As a comparison, samples were purchased of two bottles of cooking oil made from coconut with the Bo brand and the ID brand, as well as oil made from Canola which is imported oil at the Lai Lai Express supermarket at S 7°57’54.5544” and E 112°36’16.1532”.

Red palm oil and red palm olein is obtained from three sources: i) micro, small, and medium enterprise products (Usaha Mikro Kecil dan Menengah – UMKM) in Lubuk Linggau, South Sumatra; ii) company products in Bogor; and iii) company start-up products in Bandung, in collaboration with universities. The authors regret that until this manuscript had been submitted, the sample of red palm olein (minyak makan merah - M3) product from Pagar Merbau, North Sumatra — the first pilot factory inaugurated by President Jokowi, had not been received, so it could not be presented in this manuscript.

2.2 Material

Chemicals for degradation were used fenton. i.e., H2O2 30 % and Fe3SO4 7H2O, while for density separation a 30 % NaCl solution was used (all ingredients are technical chemicals), and distilled water was purchased at the Nurra Gemilang shop, Malang. A 300 mesh linen cloth (disposable) for the 2nd stage of sample filtration was purchased online at Sumber Flitech Mandiri, Jakarta via Shopee, while a stainless filter with a mesh size of 5 mm was used for the 1st stage of filtration. This study also used glass equipment, comprising glass beakers, determining flasks, pipettes, glass bottles, vials, glass stirrers, petri dishes, and mortar. Aluminum foil for packages in drying ovens and covering for glassware were used. Some sticker paper was also desired for sample indication.

This study used animal physics lab. for preparation, and optics lab. for MPs identification in the Department of Biology, Faculty of Science and Technology, Campus I (S 7°57’2.3328" and E 112°36’24.5592”), while polymer identification using Fourier Transform Infrared Spectroscopy (FTIR) in the research lab., Department of Pharmacy, Campus III (S 7°55’18.2136” and E 112°32’48.8076”), The State Islamic University of Maulana Malik Ibrahim, Malang East Java, Indonesia.

2.3 Microplastic analyses

Material preparation was carried out by referring to Masura et al. [61] and Yona et al. [62] modified. In general, the MPs analysis method is carried out in the stages of sample preparation, organic material degradation, density separation, sample sorting, and
observation. The preparation procedure is differentiated between solid samples (e.g., fried snacks) and liquid samples (e.g., cooking oil).

A total of 100 g of solid samples were dried in an oven (Heraeus 65L – Thermo Scientific, USA) at a temperature of 80 °C. Dry solid samples were ground with a mortar and filtered through a 5 mm sieve. The dry material was weighed (Sartorius Analytical Balance ME204, Germany) in the amount of 15 g and placed in a glass bottle. Add 30 % NaCl solution and incubate for 12 h. After incubation, 20 mL of 30 % H₂O₂ and 20 mL of Fe₂SO₄ · 7H₂O were added. Incubation was carried out again for 12 h. After the second incubation, the sample is filtered to separate liquid and solid. The liquid was centrifuged (Heraeus Labofuge 200, Thermo Scientific, USA) with the addition of 30 % NaCl solution. The clear part was heated to 70 °C in a water bath (Shel Lab 15 L, USA). Samples were cooled and filtered through 300 mesh nylon cloth. The filter cloth was washed with 30 % NaCl solution which was collected in a petridish.

For liquid samples, the same procedure is carried out, but without the oven. A total of 15 mL of liquid sample was placed in a glass bottle, plus 20 mL of 30 % H₂O₂ and 20 mL of Fe₂SO₄ · 7H₂O. Incubation was carried out for 12 h. Procedure for water bath, filtering, and washing with 30 % NaCl solution after incubation. Sample analysis was carried out in duplicate.

2.4 Identifikasi MPs

Identification of the shape, color and abundance of the MPs was observed using a stereo light microscope with 3.75× to 540× magnification (Nikon SMZ 1500, with digital camera DXM 1200C, connected to Hewlett-Packard TV, 12 inch). The MPs particles found were documented, and quantitative and qualitative observations were carried out. Quantitative observations include the number of particles (fibers, filaments, fragments, and granules etc.) expressed as MPs abundance (particles g⁻¹ or mL⁻¹). The abundance of MPs was calculated based on Equation (1) [Fan et al. [63]] modification.

\[ N = \frac{n}{v} \]  

Where,

N : The abundance of MPs (ind. g⁻¹ or mL⁻¹).
n : The number of MPs particles found.
v (L or g) : The amount of sample dry weight.

Next, the samples are stored in vials for further Fourier Transform Infrared Spectroscopy (FTIR) analyses (Agilent Technologies Cary 630 FTIR, USA). Wavelengths with microLab 300 software are displayed on the Lenovo AIO 910, 27 inch monitor screen. Polymer identification refers to Veerasingam et al. [64]. FTIR data have not been included in this manuscript because the analysis was not completed by the submission deadline.

3 Results and discussion

3.1 Cooking oil

Table 1 shows MPs observation data from cooking oil based on sample determination, while Table 2 shows the debris microplastic on red palm oil/red palm olein (RPO).
<table>
<thead>
<tr>
<th>Number</th>
<th>Cooking oil</th>
<th>Shape and number</th>
<th>Color and number</th>
<th>Abundance particle mL⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. PREMIUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturer BKP.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Ti. brand</td>
<td>Fiber-1</td>
<td>Black-1</td>
<td>0.07 ± 0.09</td>
</tr>
<tr>
<td>Manufacturer ISM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Bi. brand</td>
<td>Fiber-3, Fragmen-1</td>
<td>Black-2, Blue-1, Red-1</td>
<td>0.23 ± 0.14</td>
</tr>
<tr>
<td>Manufacturer MMG.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>So. brand</td>
<td>Fiber-3</td>
<td>Blue-1, Red-1</td>
<td>0.08 ± 0.02</td>
</tr>
<tr>
<td>Manufacturer SAF.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Fa. brand</td>
<td>Fiber-1, Granule-1</td>
<td>Black-1, Transp.-1</td>
<td>0.10 ± 0.05</td>
</tr>
<tr>
<td>Manufacturer Wir.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Sa. brand</td>
<td>Film-1, Granule-1, Fragmen-1</td>
<td>Black-1, Red-1, Transp.-1</td>
<td>0.13 ± 0.00</td>
</tr>
<tr>
<td>B. LITTLE MANUFACTURER</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Ao. brand</td>
<td>Fiber-2, Granule-1, Fragmen-1</td>
<td>Black-2, Blue-1, Transp.-1</td>
<td>0.29 ± 0.22</td>
</tr>
<tr>
<td>7.</td>
<td>Minyakkita brand</td>
<td>Fiber-2, Film-1, Granule-1, Fragmen-1</td>
<td>Black-1, Blue-2, Red-1, Transp.-1</td>
<td>0.28 ± 0.05</td>
</tr>
<tr>
<td>C. BULK OIL – PEOPLE’S BULK COOKING OIL (MGCR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Mergan market</td>
<td>Fiber-4, Fragmen-2</td>
<td>Black-5, Red-1</td>
<td>0.37 ± 0.05</td>
</tr>
<tr>
<td>9.</td>
<td>Oro-oro Dowo market</td>
<td>Fiber-2, Film-1, Granule-1, Fragmen-1</td>
<td>Black-3, Red-2</td>
<td>0.33 ± 0.09</td>
</tr>
<tr>
<td>D. COCONUT OIL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Bo. brand</td>
<td>Fiber-1, Film-1</td>
<td>Black-1, Blue-1</td>
<td>0.10 ± 0.05</td>
</tr>
<tr>
<td>11.</td>
<td>ID. brand</td>
<td>Fiber-1, Film-1</td>
<td>Black-1, Transp-1</td>
<td>0.10 ± 0.14</td>
</tr>
<tr>
<td>E. IMPORT – CANOLA OIL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Ma. brand</td>
<td>Fiber-1</td>
<td>Black-1</td>
<td>0.07 ± 0.00</td>
</tr>
</tbody>
</table>

Table 1 and Table 2 complements the findings of Guo et al. [44] and Battaglini et al. [45] regarding MPs contamination in cooking oil produced in the USA, Italy, and Spain because MPs debris is also present in cooking oil sold in Indonesia, especially in palm cooking oil.
Table 2. MPs contamination on red palm oil/red palm olein.

<table>
<thead>
<tr>
<th>Number</th>
<th>Red palm cooking oil (RPO)</th>
<th>Shape and number</th>
<th>Color and number</th>
<th>Abundance particle mL⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>13*).</td>
<td>Lubuk Linggau - semi solid</td>
<td>Fiber-4, Film-1, Granule-1, Fragmen-1</td>
<td>Black-3, Blue-1, Brown-1, Red-1, Transp.-1</td>
<td>0.50 ± 0.05</td>
</tr>
<tr>
<td>14*).</td>
<td>Lubuk Linggau - liquid</td>
<td>Fiber-2, Film-1, Fragmen-1</td>
<td>Black-2, Blue-1, Transp.-1</td>
<td>0.23 ± 0.05</td>
</tr>
<tr>
<td>15**).</td>
<td>Bandung liquid</td>
<td>Fiber-2, Fragmen-2</td>
<td>Black-3, Red-1</td>
<td>0.27 ± 0.09</td>
</tr>
<tr>
<td>16*).</td>
<td>Bogor A - semi solid</td>
<td>Fiber-6</td>
<td>Black-2, Blue-4</td>
<td>0.40 ± 0.00</td>
</tr>
<tr>
<td>17*).</td>
<td>Bogor B - semi solid</td>
<td>Fiber-2, Granule-1</td>
<td>Black-3, Blue-1</td>
<td>0.23 ± 0.05</td>
</tr>
</tbody>
</table>

Note:
*) Mesocarp bases: 13, 14, 16 and 17
**) CPO bases: 15
No. 16: Stored in a plastic bottle for 12 mo,
No. 17: Stored in a plastic bottle for 4 mo, and added "special treatment technology."

3.1.1 Abundance

All cooking oils (palm, coconut, and canola) in this study are contaminated with MPs (Table 1), also on red palm oil (Table 2). Cooking oil with the smallest MPs pollution was found in sample No. 12, canola oil (Ma. brand) as imported cooking oil. However, the same level of pollution was found in premium palm oil sample No. 1 (Tl. brand). The largest abundance of MPs was found in cooking palm oil sample No. 8, followed by sample No. 9, these two samples are bulk oil - people's bulk cooking oil (Minyak Goreng Curah Rakyat - MGCR) purchased from two traditional markets in the city of Malang.

High MPs contamination in bulk oil, specifically MGCR, results from the distribution process. Cooking oil is transferred from producers to distributors, sub-distributors, agents, wholesalers, and retail traders without proper packaging. Retailers further dispense the oil to consumers by measuring and placing it in plastic bags [65]. This distribution method facilitates MPs ingress through airborne particles. Additionally, MGCR is exposed to sunlight and high temperatures during transportation, exacerbating contamination. Various factors contribute to pollution, including transportation and handling methods such as pumps and scoops. These findings align with the Indonesian Ministry of Trade's Mandatory MGS (minyak goreng sawit - palm cooking oil) Packaging Policy outlined in Minister of Trade Regulation 9/2016.

Mandatory packaging implementation effectively reduces MPs contamination, as evidenced by samples No. 6 and No. 7. However, the abundance of MPs in these samples remains higher than that in premium cooking oil. This difference is attributed to the MGCR filtering process during manufacturing, which occurs only once compared to premium cooking oil (2x to 5x), aimed at cost reduction. Despite this, bulk oil distribution data from 2023 indicates that contamination levels will still exceed those of the Minyakkita brand, which uses packaging [66], consequently, palm cooking oil in the Indonesian market continues to exhibit high levels of MPs contamination.
Table 1 also shows that cooking oil in the premium category can be contaminated with relatively high levels of MPs, as shown in sample No. 2. Cooking oil—Bi. brand is produced by a large factory integrated with the 2nd largest palm oil plantation in Indonesia [67] and one of the Top Brand Award cooking oils 2023 and 2024 [58] was contaminated than other premium category cooking oils.

Table 2, illustrates the abundance of MPs in red palm oil/red palm olein - RPO, a new variant of cooking oil (M3 brand) slated to enter the Indonesian market in 2024. Introduced by the Government of the Republic of Indonesia, M3 aims to enhance the income and bargaining power of Indonesian palm oil farmers. Moreover, it offers a healthier alternative to conventional cooking oil due to its elevated levels of phytonutrients, including provitamin A, Vitamin E, and squalene. M3 is anticipated to mitigate stunting in Indonesia by not only serving as cooking oil but also being available in capsule and syrup forms as a functional food [68].

The authors experienced problems obtaining M3 samples, so in Table 2, the new cooking oil data needs to be listed. However, the five red palm oil samples in Table 2 show that all samples are contaminated with MPs. The highest MPs debris was found in sample No. 13, being the lowest in samples No. 14 and No. 17. Temporary conclusions from Table 2 are i) the semi-solid form contains higher MPs contaminants than liquid, ii) sample No. 17 even though it is in semi-solid form with "special treatment" can minimize MPs, iii) sample No. 16 (stored 12 mo) contained higher MPs than sample No. 17 (stored 4 mo), iv) samples No. 16 and No.17, although stored for 4 mo to 12 mo, did not go rancid.

Several questions arise regarding the temporary conclusions above. i) Semi-solid contains higher MPs than liquid; does this mean that stearin products (e.g., margarine, shortening, etc.) contain relatively high MPs? ii) Storing RPO up to 12 mo does not cause rancidity; is it because the antioxidants in RPO are high, so they reduce pro-oxidants? iii) MPs in 12 mo storage are higher than 4 mo; does MPs migration occur? iv) How is RPO stored? v) Is there any special treatment to minimize MPs in semi-solid form - such as virgin red palm oil as functional food? Research on improving RPO is needed to answer this research question [28, 29].

MPs abundance data presented in Table 1 were lower compared to previous research on non-palm cooking oil [42, 43]. This variance arises from differences in analysis methods; the previous researchers [42, 43] utilized hexane as the degradation and Raman for identification. In contrast, the studies in this manuscript employed modified fenton [59, 60] and light microscopy. Despite using “relatively simple methods”, the author demonstrates the presence of MPs contamination in cooking palm oil sold in Indonesia.

3.1.2 Shape and color

Table 1 and Table 2 shows the MPs shape composition in cooking oil, as follows: fiber (60.66 %), fragments (18.03 %), granules/pellets (11.48 %), and films/filaments (9.83 %). This finding differs from Battaglini et al. [45], which states that fragments dominate. However, the findings align with several previous studies, showing that fiber dominates MPs debris. In marine and river environments, fiber dominance was reported by Barrows et al. [69]; Correa-Araneda et al. [70]; Rebelein et al. [71]. MPs - fiber was dominated river bodies, due to pollution that comes from washing clothes with synthetic fibers [72, 73]. Rainfall contains the largest amount of fiber contaminants [74–80]. Additional sources of MPs fiber pollution include waste burning in incinerators or open fires and the substitution of wood with chopped plastic waste, used footwear, foam, in certain small-scale industries [81–83]. Several studies [84–86] have found that even MPs fiber can stay airborne for extended periods and be deposited thousands of kilometers away from their sources.
Samples No. 8 and No. 9 exhibit the highest MPs contamination, predominantly composed of fibers. MPs fibers are present in bulk oil, specifically MGCR, due to the single-time filtering process and the absence of packaging during distribution. Consequently, there was a potential for fiber-containing dust to contaminate MGCR throughout journey from the producer to the end consumer.

Table 1 and Table 2, also shows the color of MPs that contaminate cooking oil. Black (53.45 %) dominates, followed by blue (22.41 %), red (15.52 %), transparent (6.90 %), and brown (1.72 %). Rainwater in Jogyakarta, Indonesia, dominated by MPs fiber with a black color, which is thought to be due to abrasion from car tires that are thrown into the air and fall back to land through rainfall [87]. Researchers [88–90] support the notion of "wear and tear of tires: A stealthy source of microplastics in the environment”.

Based on the extensive discussion, MPs contamination particularly fiber particles (along with granules/pellets) in cooking palm oil originates from crude palm oil (CPO). The potential sources of this pollution include: i) Rainwater absorbed by oil palm trees, leading to the presence of MPs in palm fruit, ii) Water utilized during the processing stages in CPO refinery factories and cooking oil manufacturer, iii) MPs contamination in palm oil seeds, as evidenced by preliminary research indicating the presence of MPs in seedling media blocks and nursery pouches, despite claims of biodegradability, iv) MPs contamination stemming from cultivation activities, as indicated by the discovery of film and fragment. Film may arise from plastic sacks used for chemical fertilizers and activities of garden workers, while fragment particles could originate from multi-layer sachet waste, bottles made of hard plastic (including pesticide and herbicide bottles), and the caps of drink bottles or chemical inputs used in palm oil cultivation.

### 3.2 Indonesian fried snack

Table 3 shows MPs contamination in Indonesian fried snacks sold by street vendors in three locations around the university campus in Malang City.

<table>
<thead>
<tr>
<th>Number</th>
<th>Indonesian fried snacks</th>
<th>Shape and number</th>
<th>Color and number</th>
<th>Abundance particle g⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Snack a</td>
<td>Fiber-1, Film-1, Granule-1, Fragment-1</td>
<td>Black-2, Transp.-1, Red-1</td>
<td>0.13 ± 0.00</td>
</tr>
<tr>
<td>2</td>
<td>Snack b/thick tempeh</td>
<td>Fragment-1</td>
<td>Black-1</td>
<td>0.03 ± 0.00</td>
</tr>
<tr>
<td>Location B</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Snack c</td>
<td>Fiber-3, Fragment-1</td>
<td>Black-3, Blue-1</td>
<td>0.23 ± 0.05</td>
</tr>
<tr>
<td>4</td>
<td>Snack d/ chocolate banana</td>
<td>Fiber-2, Film-1, Fragment-1</td>
<td>Black-3, Blue-1</td>
<td>0.23 ± 014</td>
</tr>
<tr>
<td>5</td>
<td>Snack e/banana</td>
<td>Fiber-1, Fragment-1</td>
<td>Black-2</td>
<td>0.10 ± 0.05</td>
</tr>
</tbody>
</table>

Continue on the next page.
Table 3. Continue.

<table>
<thead>
<tr>
<th></th>
<th>Snack f/ flour</th>
<th>Fiber-1 Film-1 Fragmen-1</th>
<th>Black-2 Grey-1</th>
<th>0.20 ± 0.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Snack g/thin tempeh</td>
<td>Fiber-4 Film-2</td>
<td>Black-6</td>
<td>0.25 ± 0.12</td>
</tr>
</tbody>
</table>

**Location C**

<table>
<thead>
<tr>
<th>8</th>
<th>Snack h/tofu</th>
<th>Fiber-1 Fragmen-1</th>
<th>Black-2</th>
<th>0.12 ± 0.16</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Snack i/banana</td>
<td>Fiber-1 Film-1 Fragmen-1</td>
<td>Black-1 Blue-1 Transp.-1</td>
<td>0.17 ± 0.05</td>
</tr>
</tbody>
</table>

Table 3 shows that various snacks at location B contain higher MPs than location A and location C. Location B was a street vendor who is suspected of mixing plastic when frying snacks [44–49]. Sample No.7, tempeh with the highest MPs abundance and 833× higher than tempeh sample No. 2. Sample No.2 used premium cooking oil No.1, while tempeh sample No. 7 (Table 2) used MCGR — cooking oil No. 8 or No. 9 (Table 1).

The findings at location B support the suggestion that the quality of the MCGR should be improved because of the possible negative impact on public health. Another finding, is that fluorine as a flavoring for fried snacks, apparently has a negative impact. Snack No. 5 and No. 6 was a mixed snack (banana wrapped in flour). In the analysis of the separated MPs, flour as a banana wrapper contains 2× higher MPs than banana.

Supporting Table 1 and Table 2, it appears in Table 3 that fiber (48.27 %) dominates; followed by fragments (27.59 %), films (20.69 %), and granules (3.46 %). In terms of color in shape - as in Table 1 and Table 2, black dominates with 70.89 %, followed by blue (10.34 %), transparent (6.90 %), red (3.45 %) and gray (3.45 %).

Data variations resulting from deep frying at temperatures below or equal to 200 °C [91] lead to the breakdown of certain MPs into nanoplastics (< 1 µm), posing challenges for identification through optical microscopy [92]. Researchers have observed error rates ranging from 20 % [93] to 70 % [94] when using a light microscope for identification. To enhance the validity of MPs analysis, Raman Microspectroscopy (RMS) coupled with Fourier Transform Infrared Microspectroscopy (Micro-FTIR) is recommended [95–97].

Several studies highlighted the impact of nanoplastic particles on biological systems. In living organisms’ intestines, the systemic translocation of both MPs and nanoplastics is significantly influenced by particle size [98, 97]. Yustiniasari et al. [49] found significant histopathological changes in the small intestine compared to the control group. Encephala [50] demonstrated that exposure to plastic-contaminated cooking oil increased jejunal MDA by up to 98.49 %, leading to damage to the villous structure and epithelial cell death. Further, Dhewanta [48] observed spleen damage, while Cahyono et al. [51] noted kidney damage as impact MPs in cooking oil.

### 4 Future research

The authors planned and suggested future research, namely:

#### 4.1 Number of samples of cooking oil, red palm oil, and Indonesian fried snacks

In future research, the authors will increase the sample size on Table 1 and Table 2 to make the data more valid. Likewise, the authors will complete the data with used cooking oil.
4.2 Fourier transform infrared spectroscopy

The data in Table 1 and Table 2 should be enriched with Fourier Transform Infrared Spectroscopy (FTIR) analyses to identify polluting polymers, so that mitigation actions can be carried out appropriately. Likewise, the authors plan to complete the identification with Raman microspectroscopy in order to detect some of the MPs nanoparticles.

4.3 In vivo test

In future research, in vivo research will be planned on the impact of cooking oil contaminated with MPs on experimental animals, Rattus norvegicus domestica (Berkenhout, 1769), aiming should be considered by the Food and Drug Supervisory Agency (BPOM) and the National Standardization Agency - Indonesia (BSN) to improve food standards (SNI) in Indonesia. This in vivo study will also handle used cooking oil and red palm oil.

In their study, Deng et al. [99] reported that MPs measuring 5 μm and 20 μm in diameter can build up in the livers of experimental animals following 28 days of exposure to a daily dose of 0.5 mg. MPs that accumulate in different organs might potentially transfer harmful compounds from within to the surface through a mechanism called concentration gradient. These toxins can then spread to nearby tissues, leading to an immunological response [100]. Multiple studies have shown that MPs can interfere with the metabolic processes of amino acids, bile acids, and liver lipids [101]. Studies conducted on mammalian cells have demonstrated that MPs can induce oxidative stress, alter cell membranes, and activate inflammatory cells and apoptotic pathways. A study conducted on isolated hepatocyte cells from 3-year-old mice revealed the activation of Reactive Oxygen Species (ROS) and DNA damage because of exposure to MPs [102]. The presence of MPs seems to be correlated with the rise in oxidative stress in the liver. The oxidative stress and metabolic profile changes induced by MPs ultimately lead to inflammation and reduced liver function [102].

4.4 Observation of MPs sources in oil palm nurseries

Palm oil seeds have been found to harbor MPs. Initial investigations indicate the presence of MPs in both the seedling media block and nursery pouch. In response, the authors have outlined plans for bioremediation research. There is optimism that these bioremediation endeavors can be extended to oil palm plantations, aiming to produce CPO with minimal MPs.

4.5 Migration of MPs in plastic bottle

The authors aimed to investigate the migration of MPs within PET plastic bottles to ensure the safety of cooking oil packaging. This research is crucial due to findings by Guo et al. [44] that reported no MPs migration in non-palm cooking oil. However, other studies have highlighted chemical deterioration of cooking oil during storage and the leaching of bottle constituents, such as plasticizers [103, 104].

5 Conclusion and suggestion.

The investigation showed that 16 cooking oil brands were contaminated with MPs. The most minor abundance of MPs (0.07 ± 0.09) mL⁻¹ particle is in the Tl. brand, a premium cooking oil that matches imported canola oil (Ma. brand). Bulk cooking oil is contaminated with the highest MPs (0.37 ± 0.05) mL⁻¹ particle, but the contamination can be reduced with
packaging, as shown in the Minyakkita brand (0.28 ± 0.05) mL⁻¹ particle. Red palm oil has contamination, i.e., (0.23 ± 0.05) mL⁻¹ to (0.50 ± 0.05) mL⁻¹ particles. Investigations at three street vendors of fried food showed that the snacks were contaminated with MPs, amounting (0.03 ± 0.00) mL⁻¹ to (0.23 ± 0.14) mL⁻¹. Fiber (48.27 % to 60.66 %) and black (53.45 % to 75.86 %) particles dominate the pollution in cooking oil and fried snacks.

Considering MPs’ harmful impacts on human health, comprehensive research on minimizing MP pollution in palm cooking oil should be carried out. This action must be carried out as a campaign for healthy Indonesian palm oil cooking.

The authors express their gratitude to the Directorate of Research and Community Service, University of Muhammadiyah Malang (DPPM - UMM), which has funded this research with letter No. E.2a/811/BAA-UMM/viii/2023. Heartful thanks are extended to Bapak Bayu Agung Prahardika (Optic Lab – UIN, Malang), Ibu Tyas Nyonyita Punjungsari and Bapak Muhammad Basyaruddin (Animal Physics Lab. UIN, Malang), Ibu Vera Vania, and Ibu Fauziyah Eni Purwaningsih (Research Lab. UIN, Malang) for supporting this research.

Reference

32. D. Rachmawati. KSP Usul Aturan DMO Minyak Goreng Dirombak, Begini Penjelasannya [KSP Proposes Overhaul of Cooking Oil DMO Rules, Here's the Explanation] [Online] from
A. Arianti, J. Darma Agung, 31,5: 26–36 (2023) [in Bahasa Indonesia]
http://dx.doi.org/10.46930/ojsuda.v31i5.3681

https://doi.org/10.1111/1750-3841.15802

https://doi.org/10.3390/toxics9090224

https://doi.org/10.3390/ijms21051727

https://doi.org/10.1016/j.scitotenv.2019.134254

https://doi.org/10.1016/j.scitotenv.2022.157857

https://doi.org/10.1016/j.scitotenv.2019.134455

https://doi.org/10.1016/j.heliyon.2023.e20440

K. Blackburn, D. Green, Ambio, 51: 518–530 (2022)
https://doi.org/10.1007/s13280-021-01589-9

X. Guo, H. Dai, J. Gukowsky, X. Tan, L. He, Food Packag. Shelf Life, 38,101122 (2023)
https://doi.org/10.1016/j.fpsl.2023.101122

https://doi.org/10.1016/j.foodchem.2024.138567

https://repository.unair.ac.id/id/eprint/4518/


54. M.F. Amir, M. Nidhal, A. Alta, Policy Brief, 1, 16: 1–16 (2022) https://doi.org/10.35497/558662


66. L. Anisah, Bulan Depan, Kemendag akan Undang Industri untuk Bahas Evaluasi Harga MinyakKita [Next month, the Ministry of Trade will invite industry to discuss oil price evaluation] [Online] from https://industri.kontan.co.id/news/bulan-depan-
Redaksi SawitKita, *Genggam Aset Rp42.6 Triliun, Sinar Mas Jadi Perusahaan Sawit Terbesar di Indonesia* [Holding IDR 42.6 Trillion in Assets, Sinar Mas Becomes the Largest Palm Oil Company in Indonesia] [Online] from https://sawitkita.id/genggam-aset-rp426-triliun-sinar-mas-jadi-perusahaan-sawit-terbesar-di-indonesia/#:~:text=Sinar%20Mas%20Agro%20Resources%20and%20Technology%20(SMART)%20Menjadi%20Perusahaan%20Sawit%20Terbesar%20di%20Indonesia, (2023) [in Bahasa Indonesia]


