

Article

A Study on Microplastic Emission from Disposable Straws and Its Dietary Relevance

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Abstract

This study systematically investigates microplastic (MP) release from polypropylene (PP) and polylactic acid (PLA) straws across beverage matrices (deionized water, cola, and skim milk) under thermal variations. A laboratory simulation system was developed to quantify MP release at ambient temperature (25 °C) and characterize size reduction across thermal gradients (25 °C, 45 °C, and 65 °C). The integrated analytical approaches combining Fourier-transform infrared spectroscopy (FTIR), micro-FTIR, scanning electron microscopy (SEM), and optical microscopy were employed to systematically quantify and characterize MPs in terms of abundance, morphological features, and polymer composition. The findings reveal that PP straws released significantly higher MP quantities (26–28 particles/straw) than PLA counterparts (18–26 particles/straw) at 25 °C, with a pronounced burst release phase occurring within the initial 5 min of usage of straws. Thermal escalation experiments demonstrated progressive MP size reduction for both PP and PLA groups, with elevated temperatures inducing particles into smaller particles.

Keywords: disposable straws; microplastics release; polylactic acid (PLA); polypropylene (PP); food contact material



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1. Introduction

Disposable plastic products have become ubiquitous in daily life, bringing convenience but also raising concerns about microplastic (MP) pollution [1–3]. Food-contact plastics, which account for nearly 40% of global plastic production, are a major source of human MP exposure [4–7]. Recent studies confirm that everyday items can shed microplastics (MPs) into our food and drinks [8–11]. For example, single-use paper cups can release on the order of 10^3 MP particles into a single cup of hot beverage [12–14], and the brewing of a plastic tea bag at 95 °C can generate an astonishing ~11.6 billion MP particles (along with 3.1 billion nanoplastic particles) per serving [15]. These findings highlight that seemingly benign consumer products are significant sources of microscopic plastic debris that can be ingested.

Plastic drinking straws, in particular, pose a critical environmental and health challenge due to three factors: their ubiquitous use, low recycling rates, and persistence in the environment [16–18]. A straw typically serves a beverage for only a few minutes, yet if discarded, it may persist for centuries before degrading [19]. During the COVID-19 pandemic, reliance on single-use plastics (including straws) increased, which exacerbated plastic pollution [16,20]. However, until recently little research has addressed whether straws are a significant contributor to MP pollution. This gap is noteworthy, as straws

provide a direct pathway for MPs to enter the human body (via beverages), and their small size and prevalence in litter have prompted regulatory actions in some regions.

Polypropylene (PP) has been the most common material for disposable straws, but its non-degradable nature means PP straws that escape waste management can accumulate in ecosystems [21,22]. Environmental concerns over PP straws have driven the search for sustainable alternatives [23,24]. One prominent replacement is polylactic acid (PLA), a bioplastic derived from renewable resources that is marketed as biodegradable [25,26]. Recent efforts have focused on improving PLA straw performance—ensuring adequate strength [27,28], and, importantly, hydrolytic stability (resistance to falling apart in liquids) [29,30]. PLA straws have gained popularity as an eco-friendly choice, but it remains unknown how prone they are to generating MPs during actual use [31,32]. To date, there is a lack of comprehensive data comparing MP release from PLA straws versus conventional PP straws under realistic usage conditions.

In light of this, our study was designed to systematically compare MP release from PP and PLA straws under various common beverage conditions. We developed a laboratory simulation of drinking through a straw, testing three beverage types (water, a carbonated cola drink, and milk) at three temperatures (25 °C, 45 °C, and 65 °C). Released particles were collected over time and analyzed using optical microscopy (for counting and size distribution), micro-FTIR spectroscopy (to confirm polymer identity of particles), and SEM (to observe particle morphology). By quantifying and characterizing the MPs from each straw type, we aim to answer: Does using a PLA straw actually reduce MP ingestion compared to PP? How do temperature and beverage composition affect MP release? The outcomes of this work will provide scientific guidance on the “dietary relevance” of disposable straw usage—i.e., implications for consumers’ MP intake—and inform stakeholders seeking to balance convenience with health and environmental safety.

2. Materials and Methods

2.1. Experimental Design and Release of MPs from PP and PLA Straws

Commercially available PP and PLA straws were employed in this experiment. Initially, each straw was individually unpacked and connected using sealing film to form an extended MPs collection system. The assembled system was secured to a pre-cleaned (subjected to ultrasonic treatment before each experiment) water pump and positioned at the bottom of a beaker containing the test beverages (DI water, cola, and skim milk). With the distal end of the straw immersed in the liquid phase, a closed-loop recirculation system was formed. Upon activation of the water pump, this system was used to mimic the human drinking process (Figure 1).

The experimental system introduced 250 mL of beverage samples into PP and PLA straws, with sequential sampling conducted at predetermined intervals (0–120 min). Released MPs were collected via vacuum filtration through 3 µm stainless-steel membranes at each sampling point. Particle quantification was performed under an optical microscope (CX43, Olympus, Tokyo, Japan). To ensure data reliability, quantitative analysis was restricted to MPs larger than 20 µm that were visually identifiable under optical microscopy [33,34].

Experimental Design

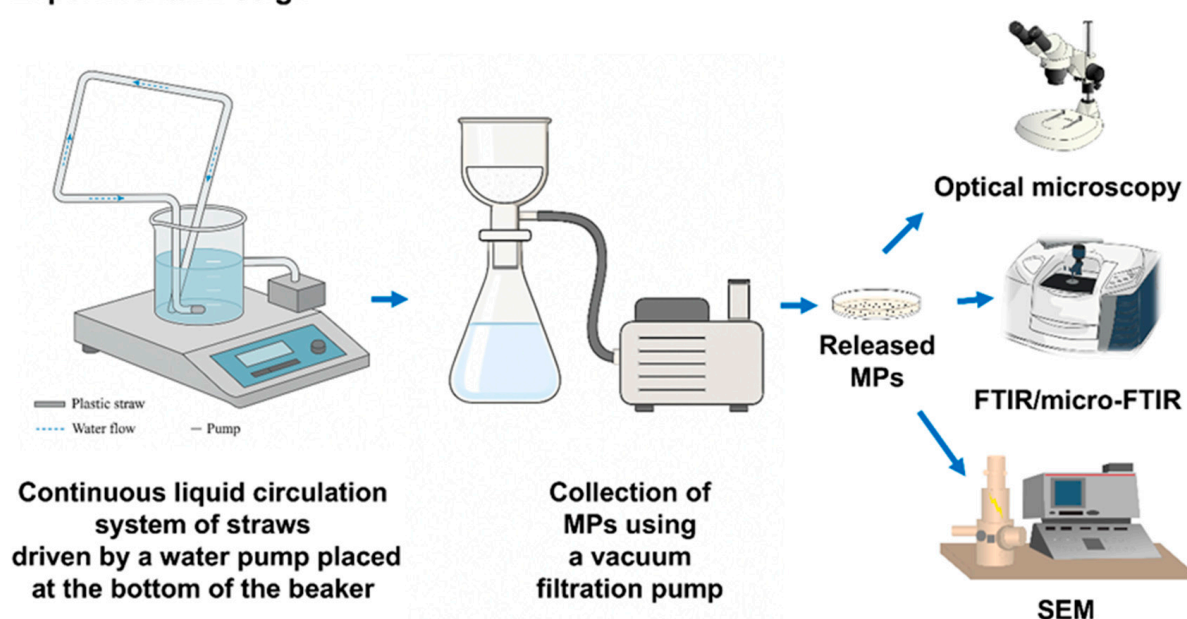


Figure 1. General procedure for the characterization of the MPs released from straws.

2.2. Identification of Released PP and PLA MPs

The collected MPs on filter membranes were analyzed using a micro-FTIR spectrometer (Nicolet iN10, Thermo Fisher Scientific, Waltham, MA, USA). In addition, pristine plastic straws were cut into $1 \times 1 \text{ cm}^2$ specimens and subjected to characterization via ATR-FTIR spectrometer (Shimadzu, Kyoto, Japan). Spectra were recorded in the $4000\text{--}600 \text{ cm}^{-1}$ range with a total of 48 scans.

2.3. Morphological Characterization of Released MPs by SEM

SEM (SU8100, Hitachi High-Tech, Tokyo, Japan) testing was performed to gain further insight into the morphologies of collected MPs on the filters. The samples were analyzed at an acceleration voltage of 4 kV. SEM images were acquired at magnifications ranging from $50\times$ to $10,000\times$ to investigate the surface morphology of released MPs.

2.4. Contamination Prevention and Control Experiment

To prevent potential contamination of the samples, nitrile gloves and laboratory coats (100% cotton) were worn during the experimental process. Before the commencement of all experiments, the gloves were thoroughly cleaned with deionized water. The glass beakers and petri dishes were then cleaned and dried using ultrasonic devices. The ultrapure water used throughout the experimental cleaning process was sourced from the Millipore Direct-Q*5 ultrapure water system.

A blank control experiment was conducted to ensure that no exogenous MPs were introduced during the experimental procedures. Glass straws were used as replacements for the experimental PP and PLA straws to simulate drinking behavior in deionized (DI) water at 25°C .

3. Results

3.1. MPs Release from Disposable Straws and Micro-FTIR Identification of MPs

The comparative analysis of MP release from PP and PLA straws during 2 h of usage under controlled laboratory conditions (25°C) revealed distinct material-dependent MP release profiles (Figure 2). PP straws exhibited slightly higher MPs release across the three

experimental conditions compared to PLA straws. The PP straws released MPs ranging from 28 ± 1 (DI water) to 28 ± 2 (cola) to 27 ± 2 particles/straw (skim milk), whereas PLA straws exhibited lower release of 18 ± 1 (DI water), 26 ± 2 (cola), and 19 ± 1 particles/straw (skim milk), with the amount of PLA MPs released into cola greater than that in water or milk (Figure 2). Control experiments using glass straws revealed detectable background particulates (2–3 particles/straw) within the same experimental system, with quantities much lower than the MPs released from PP and PLA straws. All reported values represent net MPs release, calculated by subtracting background particle counts derived from glass straw controls in identical groups.

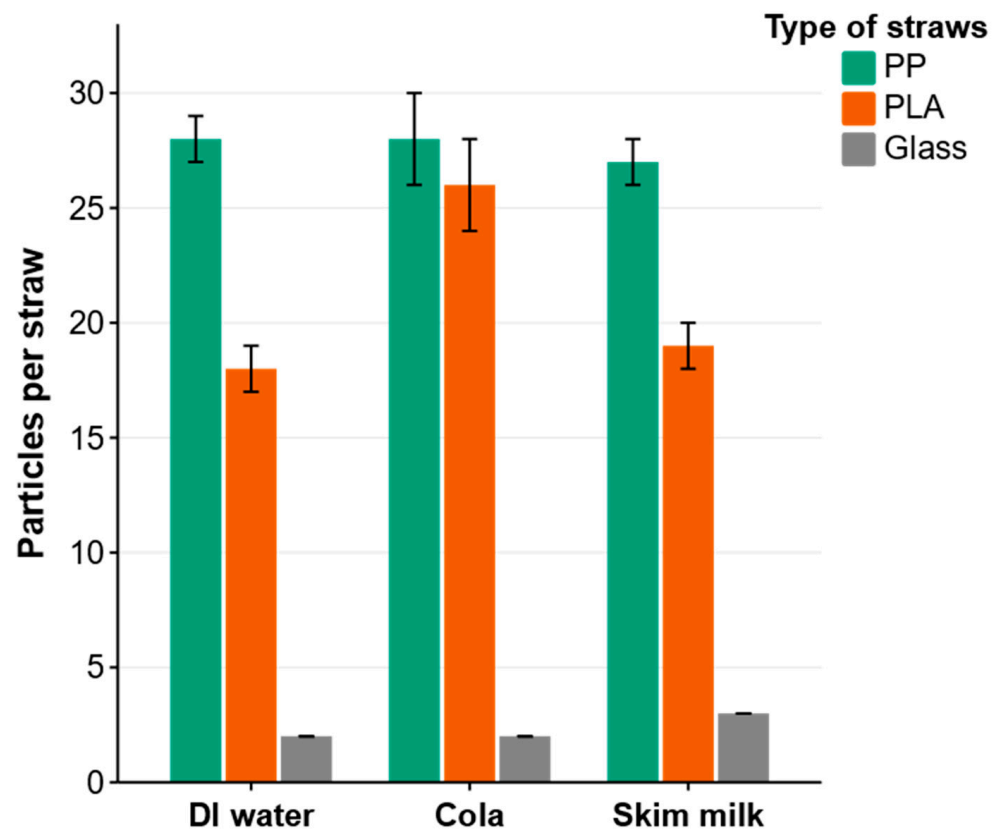


Figure 2. Quantitative analysis of PP and PLA MPs released from PP and PLA straws in DI water, cola, and skim milk matrices after 2 h experiment at 25 °C, with glass straws serving as blank control.

The time-dependent MP release profiles of PP and PLA straws at 25 °C exhibited distinct phase characteristics (Figure 3). During the critical initial 5 min release period—selected based on a survey where most people prefer to consume their beverage within a shorter time of obtaining it [35]—PP straws demonstrated pronounced burst release behavior, releasing 20 ± 2 (71.47% of 2 h total), 24 ± 1 (85.71%), and 19 ± 1 (70.37%) particles/straw for DI water, cola, and skim milk groups, respectively. Comparatively, PLA straws exhibited significantly lower MP release during this burst phase, with quantities of 14 ± 1 , 14 ± 2 , and 15 ± 1 particles/straw across corresponding beverage matrices. This differential release behavior provides empirical support for selecting PLA straws in typical drinking scenarios. Subsequent temporal release displayed gradual attenuation before stabilizing.

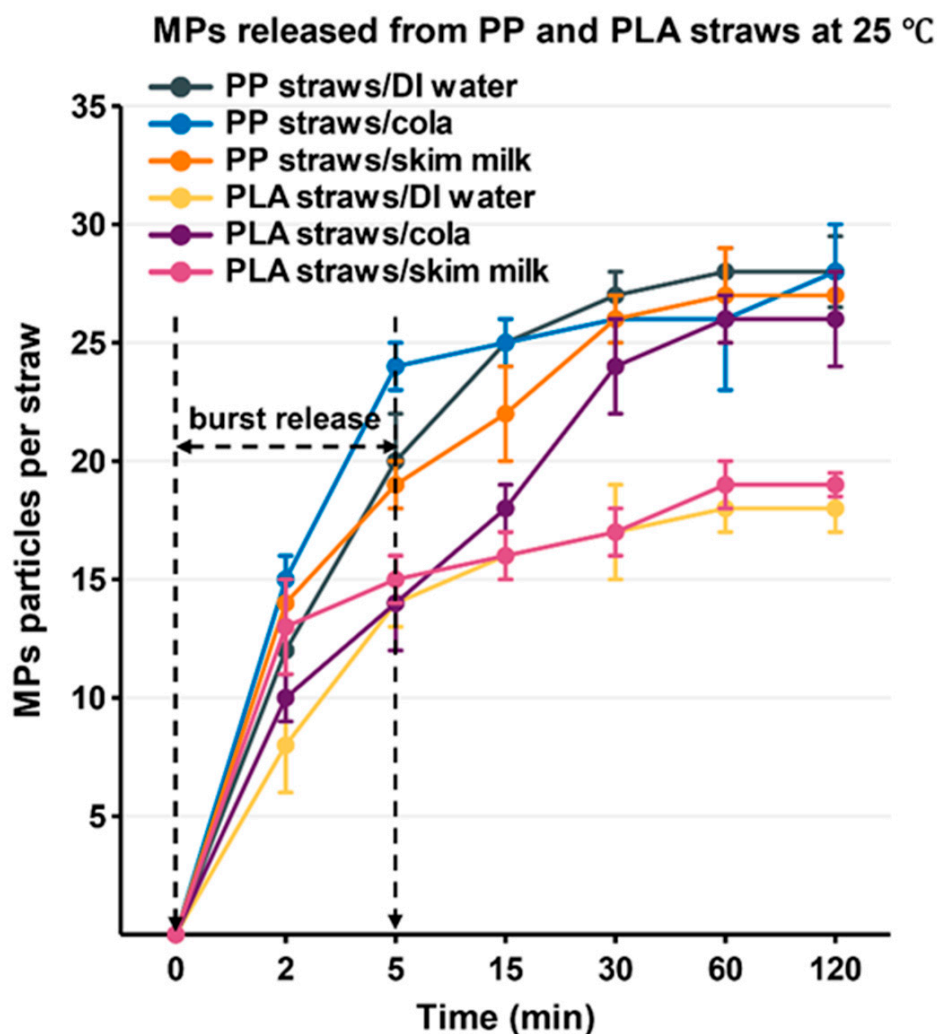


Figure 3. Time-dependent MPs release profiles from PP and PLA straws in aqueous matrices (DI water, cola, and skim milk) under controlled temperature (25 °C).

Figure 4 shows the morphology and size distribution of MPs released from PP and PLA straws in DI water, milk, and cola at 25 °C. The collected MP particles appear as irregularly shaped fragments, and the characteristic sizes of the MPs vary notably between conditions: for instance, a representative PP MP from the DI water sample is about 114 µm in diameter (Figure 4a), whereas the PLA straw in DI water produced a larger fragment around 218 µm in size (Figure 4b). A few smaller MP particles released from PP and PLA straws in the milk and cola were also observed—PP MPs in skim milk around 68 µm, and that in cola around 36 µm (Figure 4c,e). PLA straws released the particle in skim milk (~34 µm, Figure 4d) and the particle in cola (~49 µm, Figure 4f). The inclusion of higher-magnification SEM images reveals morphology details of MPs such as cracked edges and rough surfaces (Figure 4a'–f'), indicative of mechanical breakage from the straw material in experiments. Figure 4B summarizes the size distribution of the released MPs for each straw type in each liquid. Under the 25 °C conditions, both PP and PLA straws released a substantial fraction of relatively large MP fragments (i.e., those > 60 µm) among all particles ≥ 20 µm. Specifically, PP straws released MPs > 60 µm at proportions of 82.35% (DI water), 81.34% (milk), and 85.97% (cola), while PLA straws released > 60 µm particles at 86.67% (DI water), 86.03% (milk), and 80.46% (cola). This quantitative size-distribution analysis confirms that both PP and PLA straws shed sizable fragments under ambient-temperature use, with a particularly high large-particle fraction in each beverage condition.

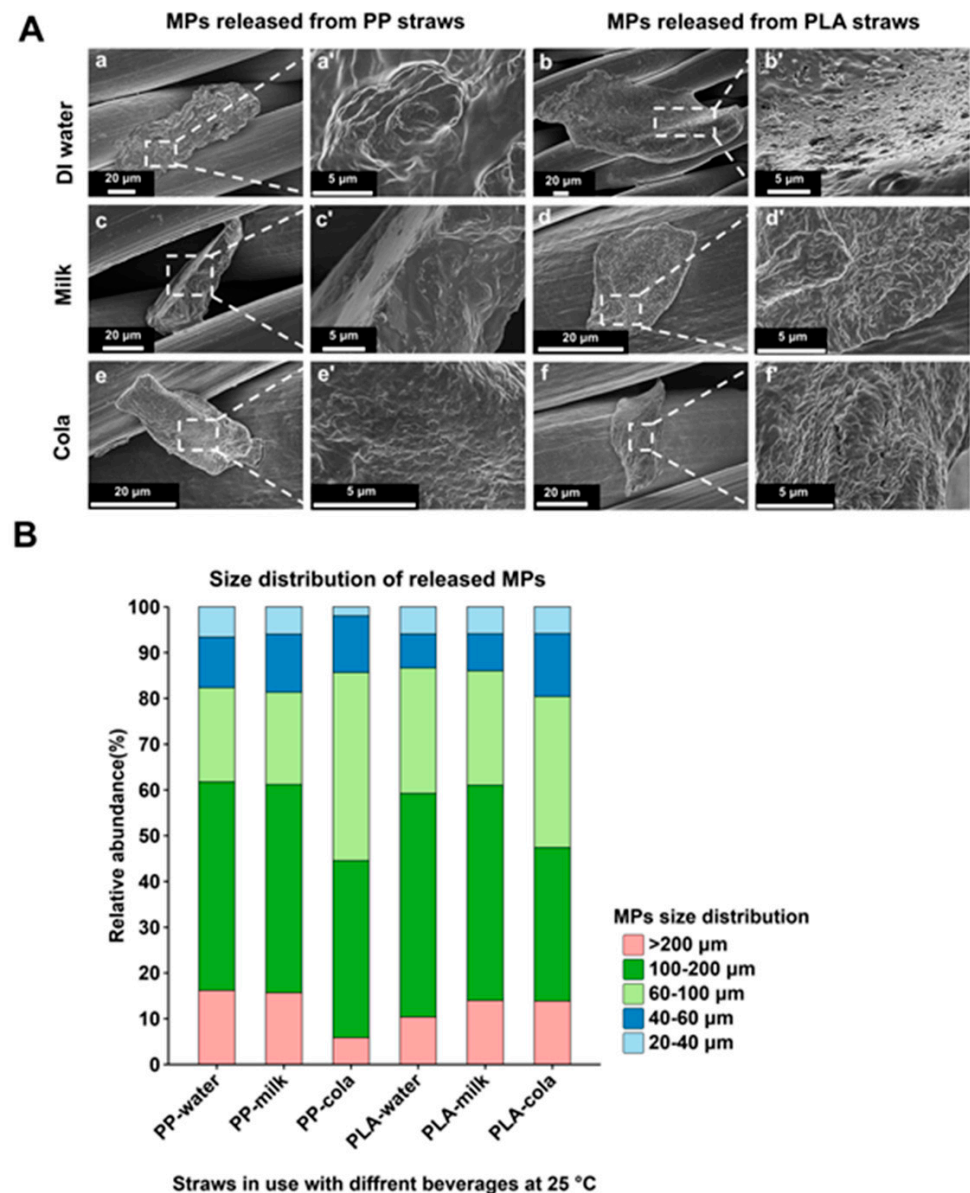


Figure 4. (A) The morphology of PP and PLA MPs released from PP and PLA straws in DI water, milk, and cola at 25 °C, respectively (a–f). MPs were collected on a stainless-steel filter membrane (3 μm); high-magnification SEM images of MPs show roughness and micro-defects from mechanical wear (a'–f'). (B) Particle size distributions of released MPs from PP and PLA straws in the same beverage samples.

Micro-FTIR spectral analysis was conducted on released particles (Figure 5). The FTIR spectra of PP straw-derived MPs exhibited characteristic peaks of PP: CH₃ swing (971, 1166 cm^{-1}), CH₃ bend (1378 cm^{-1}), CH₂ bend (1459 cm^{-1}), along with CH₂ symmetric/asymmetric stretches (2836/2916 cm^{-1}) and CH₃ symmetric/asymmetric stretches (2874/2956 cm^{-1}) [36–39]. The PLA test group yielded infrared spectra that matched PLA characteristic peaks reported in the previous literature [40,41]: carbonyl (C = O) (1749 cm^{-1}) and hydrocarbon (C-H) groups (2930 cm^{-1}), corresponding to the polar ester bonds (carbonyl) present in the PLA components [42].

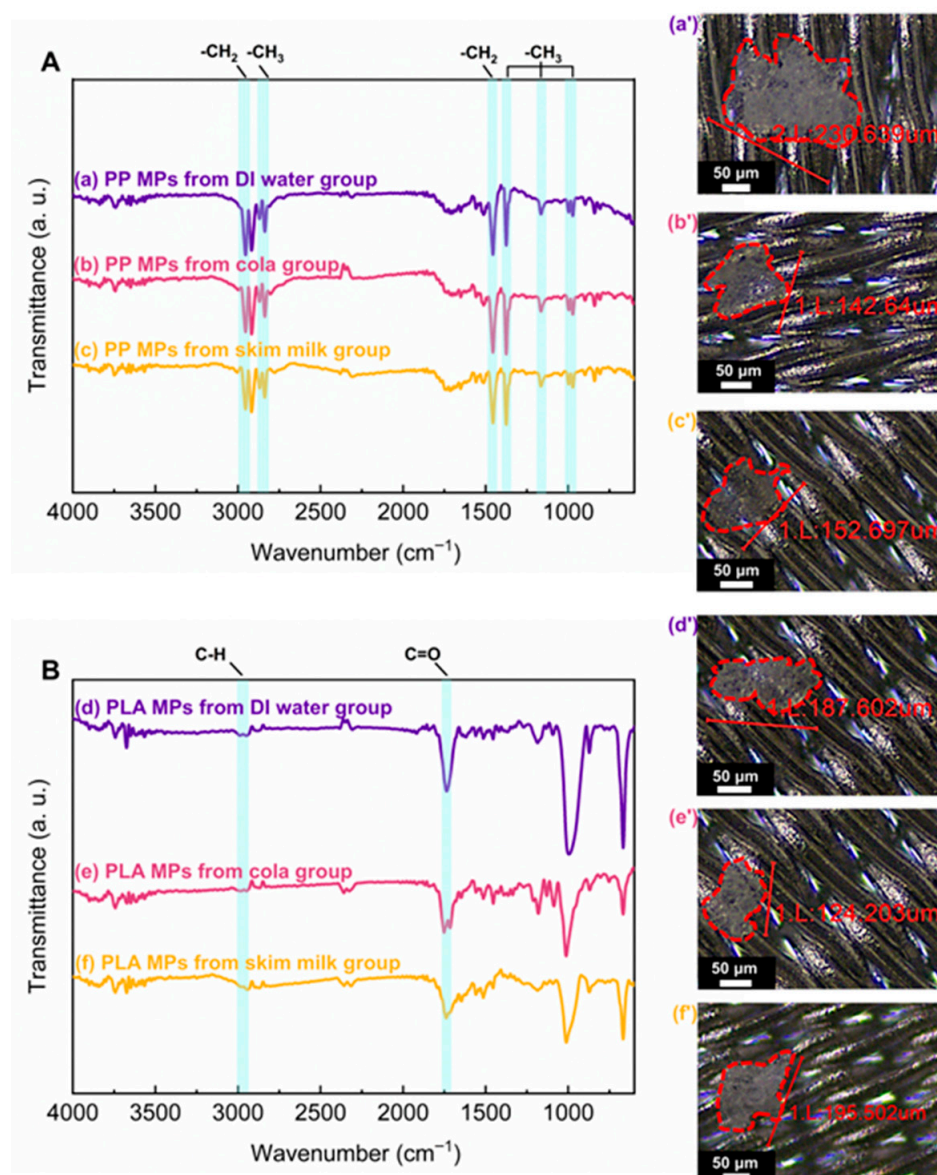


Figure 5. (A,B) characteristic micro-FTIR spectra of MPs released from PP and PLA straws in different beverages (25 °C). (a–c) micro-FTIR and (a'–c') the optical images for PP MPs from PP straws used in DI water, cola, and skim milk; (d–f) micro-FTIR and (d'–f') the optical images for PLA MPs from PLA straws under identical beverage conditions.

3.2. The Relationship Between the Size of MPs Released from PP/PLA Straws and the Temperature of Usage

As shown in Figure 6, the size of MPs released from both PP and PLA straws decreases with increasing temperature (25 °C, 45 °C, and 65 °C). Given a previous study, PP has a low glass transition temperature (T_g) around 0 °C [43]. When experimental temperatures exceed the T_g of PP and temperature-dependent experiments persist for a while, PP may exhibit progressive ductility enhancement, enabling sustained surface deformation that fragments released PP-MPs into smaller particles [44]. Specifically, released MPs from PP straws showed a median size reduction from 129 μm at 25 °C to 87 μm at 65 °C in DI water and from 130 μm at 25 °C to 115 μm at 65 °C in skim milk (Figure 6a,b). This size reduction is attributed to the enhanced physical activity of the polymer as the experimental conditions for PP straws exceed the T_g of PP, which facilitates thermal deformation of the PP MPs, enhancing the formation of cracks and defects and promoting particle adsorption on the MP surface, as observed in high-magnification SEM images (Figure 7a',b') [45–47].

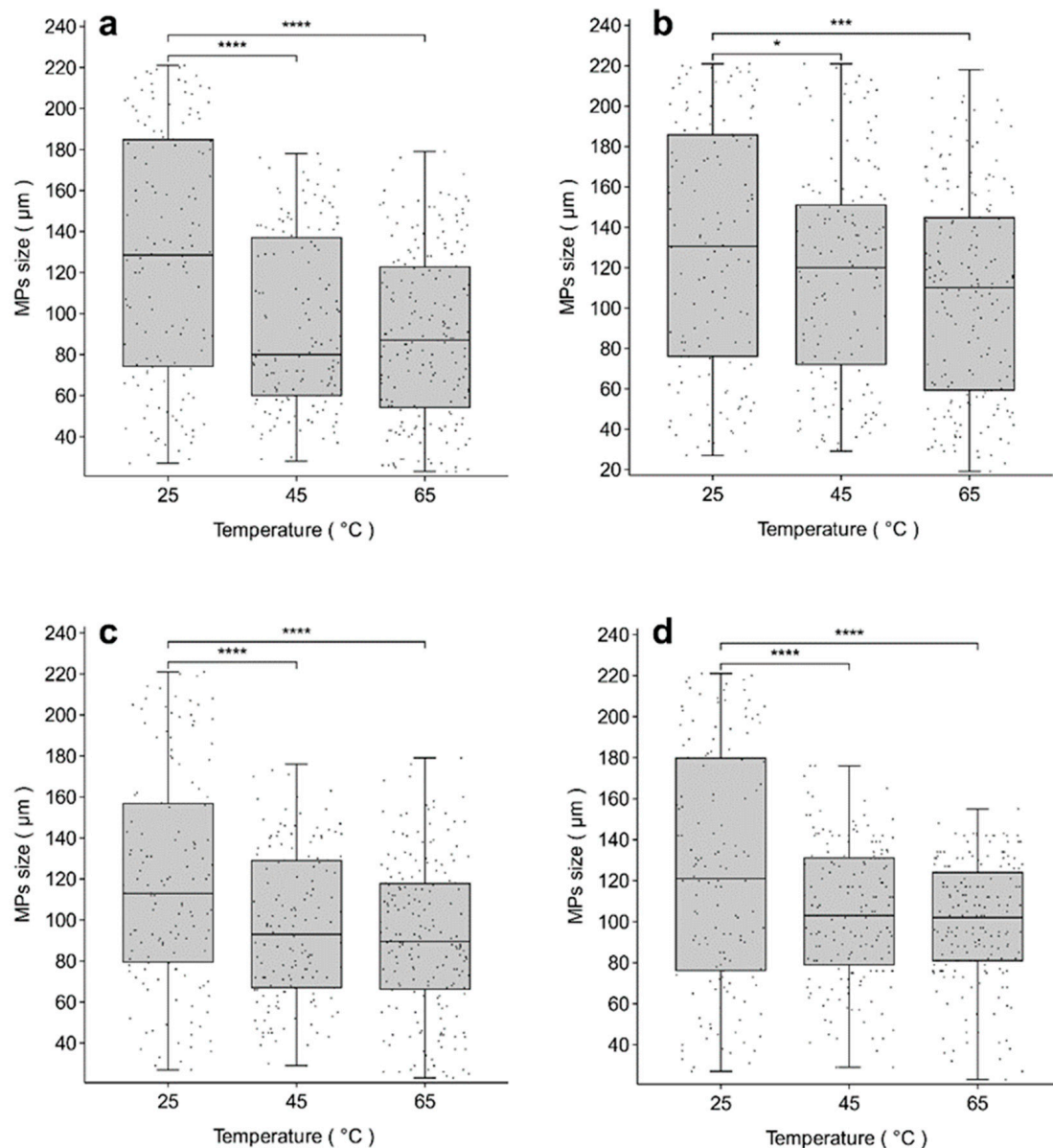


Figure 6. Temperature-dependent size distribution of MPs released from PP straws used in DI water (a) and skim milk (b), and MPs released from PLA straws used in DI water (c) and skim milk (d) at 25 °C, 45 °C, and 65 °C, respectively. Released MPs show monotonic size decline with temperature increasing (a–d). * Asterisks indicate significance levels: $p < 0.10$ (*), $p < 0.05$ (**), and $p < 0.001$ (***).

Similarly, MPs released from PLA straws also showed thermal shrinkage behavior of MP size, with median sizes decreasing from 115 μm at 25 °C to 90 μm at 65 °C (PLA/DI water group, Figure 6c) and from 123 μm at 25 °C to 101 μm at 65 °C (PLA/skim milk group, Figure 6d). The resultant compressive stress generated by the thermal shrinkage of PLA MP size led to a more compact structure in the released MPs, with the appearance of cracks and defects and particle adsorption, as seen in SEM images (Figure 7c',d'). This is similar to previous findings with PLA-lined paper cups under thermal conditions [48].

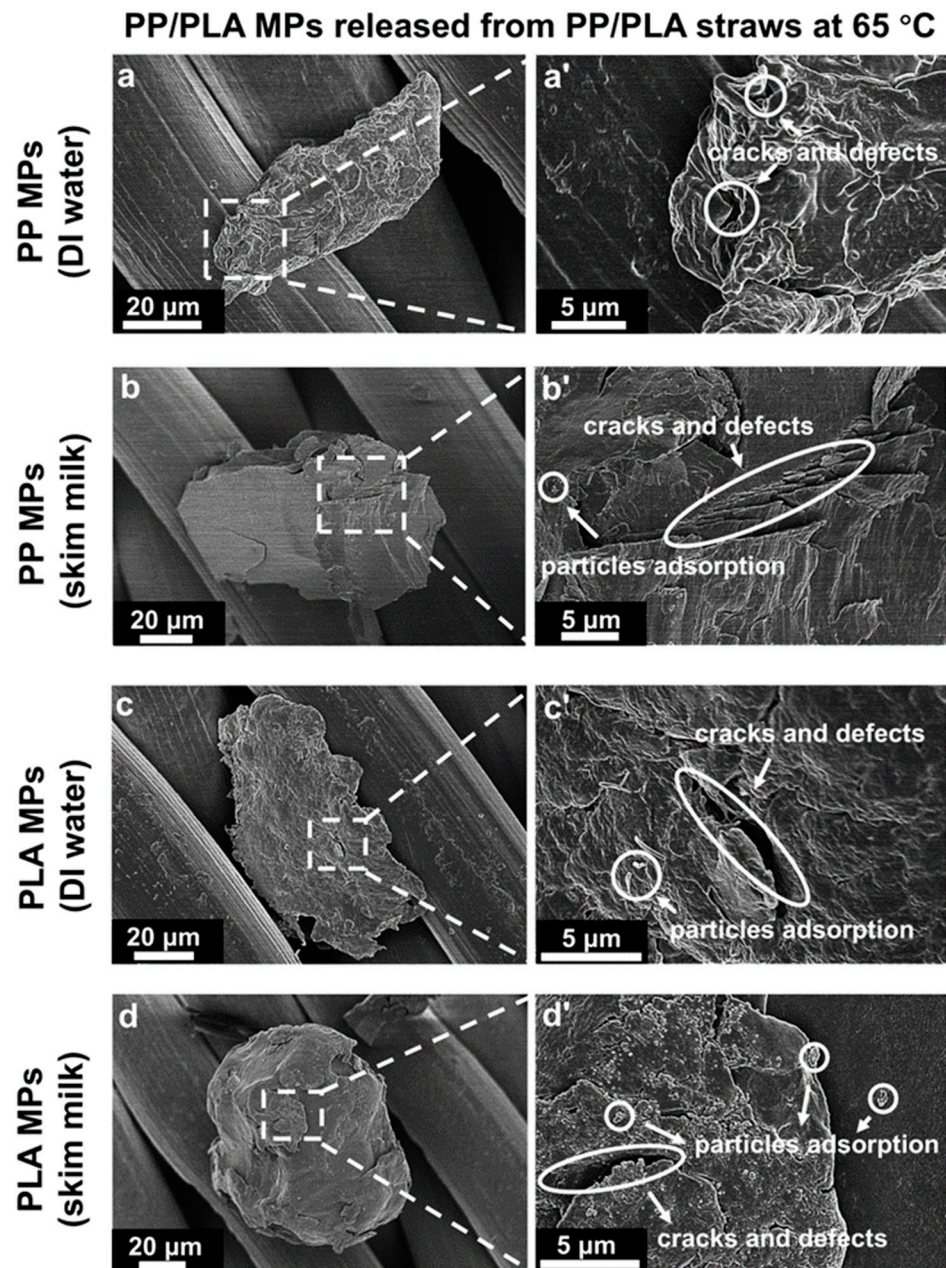


Figure 7. SEM morphology of MPs released from PP and PLA straws used in DI water and skim milk at 65 °C. (a,b) PP MPs released from DI water and skim milk group; (c,d) PLA MPs under identical liquid conditions. (a'–d') high-magnification SEM images of released PP and PLA MPs, respectively.

4. Discussion

By focusing on beverage ingredients, material types of straws, and usage temperature, we observed distinct MP release characteristics for PP and PLA straws. PLA drinking straws release significantly fewer MP particles than PP straws under identical conditions due to differences in both manufacturing processes and material properties. PP straws, typically produced by high-speed melt extrusion and mechanical cutting, often retain weak points and debris, such as tiny burrs at the cut edges, which readily detach during use [49,50]. In contrast, PLA straws, which require more controlled extrusion and slower cooling due to their thermal sensitivity, result in smoother surfaces with fewer residual particles [50]. Regarding material properties, the higher ductility of PP allows it to deform under mild stress, leading to wear and more MP release, while the rigidity of PLA reduces deformation, limiting particle release [50]. This means that under mild stresses (such as

sipping or stirring in a drink), the softer structure of PP straws could undergo stronger surface abrasion than PLA straws to release more MPs [51].

PLA straws immersed in carbonated cola released significantly more MPs at 25 °C than they did in water or milk. This behavior can be attributed to PLA's sensitivity to hydrolytic degradation: the cola's acidity ($\text{pH} \approx 2.5$, due to phosphoric and carbonic acids) likely accelerates the hydrolysis of PLA's ester linkages. Acid-catalyzed hydrolysis weakens the PLA polymer matrix, causing it to fracture into more numerous and finer fragments [52,53]. These results are consistent with Yang et al. (2023), who reported that PLA-based cup materials release higher levels of microparticles under acidic conditions than conventional plastics [48]. By contrast, PP is a hydrophobic polyolefin with no acid-sensitive bonds, so PP straws exhibited little change in particle count between water and cola (28 ± 2 vs. 28 ± 1 particles/straw). Even so, PP fragments in cola were slightly smaller, suggesting that acidity can still roughen the polymer surface [54]. Together, these findings underscore that beverage chemistry strongly influences MP generation: a "biodegradable" straw such as PLA may degrade more readily in acidic beverages than in neutral water, an important consideration for its practical performance [55].

Burst release of MP particles from PP and PLA straws in the first 5 min is largely due to pre-existing loose fragments on the straw surface from manufacturing and packaging. Straw fabrication (extrusion and cutting) could produce microscopic debris that clings to the straw [56]. Upon opening new PP or PLA straw packages, one finds these primary MPs already on the surface, and indeed SEM images (Figure S1) show many attached particles at 0 min that largely decrease by 5 min. Initial 5 min contact of beverages makes these weakly bound particles release from the inner surfaces of PP and PLA straws, causing a rapid "burst" of MP release. The propensity for such release behavior of attached particles during the burst release phase also reflects intrinsic material properties [50]. The low surface adhesion of these fragments makes them easy to wash off. Furthermore, packaging and handling contribute to initial contamination—studies of bottled water, for example, found that PP fragments from caps enter the product during the bottling process [57]. Comparable phenomena are seen in other polymer products, where a high initial release of MPs occurs on first use (e.g., a single plastic tea bag can shed on the order of 10^{10} plastic particles when first steeped [58]). Thus, the early burst release from PP and PLA straws is explained by attached MPs on inner surfaces from manufacturing and the material properties that govern fragment generation and detachment, consistent with the observed quantities of released PP and PLA MPs between 0 and 5 min [50,56–58].

After this rapid initial shedding, the release rate of MPs slowed dramatically and reached a plateau by roughly 60 min. Beyond one hour, MP counts increased only marginally, indicating that most easily dislodged fragments had already been released. This plateau reflects a quasi-steady state in which loosely attached debris is depleted and further degradation of the straw material is minimal under the experimental conditions. Similar behavior has been reported in other polymer-contact studies, where a pronounced early release of MPs is followed by a leveling as the system approaches equilibrium [59].

Once the "easy-to-remove" debris is washed away, far fewer weakly bound fragments remain on the straw surface [60]. By about 60 min, the population of readily detaching MPs has been effectively exhausted, causing the release rate to slow and the cumulative count to stabilize. Beyond the first hour of continuous recirculation, any additional MPs are supposed to originate from new mechanical abrasion or chemical breakdown of the intact polymer—processes that occur at a much lower rate under our constant flow-rate and temperature conditions [59]. Breaking intact straw material into fresh MPs requires more energy than simply washing off existing debris, so new fragments form only sporadically and in small numbers.

Figure 4A shows high-magnification SEM images of MP particles collected from PP and PLA straws after 2 h immersion at 25 °C in DI water, cola, and skim milk. In every case, particle surfaces display irregular textures—such as cracked edges and rough surfaces—indicative of mechanical wear or pre-existing stresses during detachment, rather than thermal degradation [61]. These surface defects are visibly different from the more ordered cracks produced by thermal aging at 65 °C (Figure 7). Notably, PP-derived MPs tend to be larger with relatively smooth surfaces, whereas PLA-derived fragments are smaller and exhibit more irregular shapes. This contrast is most pronounced in the acidic cola condition, where PLA MPs appear highly fragmented. The elevated count and reduced size of MPs in the PLA/cola group are consistent with acid-catalyzed hydrolysis of PLA's ester bonds, which accelerates polymer breakdown [62].

Figure 4B presents the corresponding particle-size distributions. These quantitative trends of releasing relatively large MP fragments from PP and PLA straws under ambient temperature align with the abundance patterns observed in Figures 2 and 3 and complement the analyses of thermal reduction in size of released MPs in Figure 6, demonstrating that material types, beverage conditions, and usage temperature jointly govern MP characteristics from straws.

The observed reduction in MP size with temperature is explained by the thermal behaviors of PP and PLA straws; both materials undergo thermal shrinkage, which increases the possibility of smaller MPs being release [63]. For PP MPs, as the temperature rises, the thermal effect leads to deformation and wear, facilitating fragmentation into smaller particles, while the cracks and defects observed in the SEM images suggest that higher temperatures accelerate the surface deformation. For PLA MPs, when the experimental conditions approach the glass transition temperature of PLA (T_g : 55–65 °C), the increased physical activity of PLA MPs enhances the thermal shrinkage of MPs, which subsequently results in the physical compaction of the surfaces of released PLA MPs, with cracks and defects appearing as a result of compressive forces acting on the MPs [10,63–65].

These temperature-dependent size changes in MPs are consistent with similar findings for other polymeric materials, such as polystyrene (PS) and polyethylene (PE), which exhibit thermal shrinkage when exposed to higher temperatures [66–68]. The findings underscore the importance of thermal conditions in determining the size and morphology of MPs released from plastic materials. Moreover, the presence of cracks, defects, and particle adsorption highlights the complex interaction between the polymer material, its environment, and the thermal conditions, which are crucial factors in understanding the full extent of MP release during normal usage.

The selection of experimental temperatures (25 °C, 45 °C, and 65 °C) was based on physiologically and behaviorally relevant beverage consumption conditions, as well as the need to explore boundary scenarios for MP release. Specifically, 25 °C corresponds to ambient temperature, representing the baseline for cold beverages. The 45 °C condition simulates moderately heated beverages, such as warm milk or mildly hot water, a common drinking habit among children and the elderly. Importantly, 65 °C was intentionally selected to approximate the upper limit of tolerable hot beverage temperatures for some adult populations. Although direct drinking at 65 °C may pose a burn risk for the oral mucosa, previous sensory and thermographic analyses have shown that people often prepare beverages at or above 65 °C before allowing brief cooling [58,69].

Moreover, from a materials science perspective, this temperature aligns with the glass transition temperature (T_g) of PLA, typically ranging from 55 to 65 °C [64], making it a scientifically valid stress-testing point. This threshold allows us to evaluate polymer structural behavior near thermal softening limits, which is crucial for assessing MP generation potential under thermal deformation. Similar experimental precedents have been

established in studies of plastic teabags and feeding bottles, where temperatures of 65–95 °C were used to characterize worst-case scenarios of particle release [9,35,58]. Thus, while 65 °C may exceed standard direct consumption conditions, it offers valuable insights into the thermally induced release dynamics of MPs from disposable straws under elevated stress conditions, contributing to comprehensive safety assessments.

All of this work provides new insights into the behavior of disposable straws as a source of MPs in our diet. PP and PLA straws both contribute to MP exposure, with distinct patterns influenced by material properties and usage conditions. These results fill an important knowledge gap and offer guidance to consumers (choosing safer usage practices), manufacturers (designing better straws), and policymakers (evaluating the merits of alternatives) in addressing the emerging issue of MPs in beverages. Further research should explore the long-term health implications of consuming straw-derived MPs and investigate next-generation materials that could further reduce MP release without compromising environmental sustainability [70,71].

5. Conclusions

This study provides a comparative assessment of MPs released from conventional PP versus biodegradable PLA straws under realistic usage conditions. We found that at ambient temperature (25 °C), PP straws release significantly more MP particles than PLA straws during typical use. Notably, there is a burst of MP release in the first few minutes of straw use for both materials (accounting for roughly 70–85% of total released particles), after which the release rate sharply declines and plateaus. This indicates that a majority of the MP exposure from straws would occur at the initial stage of drinking.

Temperature was a key factor affecting MP characteristics: higher beverage temperatures led to smaller-sized MP fragments from both PP and PLA. At 65 °C (a worst-case hot beverage scenario), the median particle size dropped by ~30–40% compared to 25 °C for each material, reflecting thermal softening and enhanced fragmentation. Beverage type also influenced outcomes—for instance, PLA straws in acidic cola released nearly as many MPs (and of smaller size) as PP straws, whereas in water and milk PLA consistently shed fewer particles than PP. This underscores that PLA's eco-friendliness does not eliminate MP emission, especially in challenging conditions (acidic, hot liquids).

From a practical perspective, our findings suggest that switching from PP to PLA straws could modestly reduce MP ingestion for consumers in everyday cold-drink scenarios, but neither type of straw is free of MP release. Even a PLA straw can contribute dozens of MP particles to a single drink, meaning frequent straw users may ingest substantial quantities of these particles over time (on the order of tens of thousands per year, in line with recent exposure estimates). The dietary relevance of this exposure warrants attention: while the health effects of ingesting MPs are still being investigated, reducing unnecessary sources of ingestion is prudent. For consumers, one implication is that using straws in very hot beverages should be used with caution (or avoided), as heat greatly increases MP shedding. From an industry and regulatory standpoint, our study highlights the need for developing drinking straws (and other food-contact materials) that minimize MP release. Biodegradable alternatives like PLA have benefits in end-of-life biodegradability, but improvements in their formulation might be needed to enhance stability during use (e.g., coatings or blends to resist acid hydrolysis). Likewise, simple measures such as rinsing straws (where applicable) or limiting plastic straw use to when it is necessary could mitigate ingestion of MPs.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/microplastics4030042/s1>: Figure S1: MPs attachment on the inner surface of PP and PLA straws at 0 min and 5 min during time-dependent experiments.

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