IOSR Journal of Applied Chemistry (IOSR-JAC)
e-ISSN: 2278-5736.Volume 18, Issue 2 Ser. I (February 2025), PP 43-49
www.iosrjournals.org

Photodegradation of Common Plastics: Influence of Sunlight Exposure on Weight, Surface Morphology, and Color

Anuj Dubey [a], Deepesh Bhardwaj [b*], Rupali Rastogi [a]
[a]*Department of Chemistry, ITM University, Gwalior, M.P., 474001, India*
[b]*Department of Chemistry, ITM, Gwalior, M.P., 475001, India*
anujdubey.mail@gmail.com, deepesh.bhardwaj@itmgoi.in,
rupali.rastogi.chemistry@itmuniversity.ac.in

Abstract- *Plastics, often used in everyday life, undergo photodegradation upon exposure to sunlight as a result of ultraviolet (UV) radiation. This research examines the impact of sunlight exposure on three prevalent plastics: polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET). The study examines changes in weight, surface morphology, and colour throughout a 30-day exposure to natural sunshine. Systematic laboratory measurements were performed to quantify weight reduction, examine surface degradation using morphological grading, and evaluate colour variance using visual scales. The results demonstrate that PE and PP had more weight loss, PET demonstrated notable colour degradation, and all polymers manifested differing levels of surface roughness. The results underscore the susceptibility of plastics to environmental deterioration, affecting waste management and pollution control measures.*

Keywords- *Photodegradation, Morphology, Sunlight, Weight, Polythene, Polypropylene.*

Date of Submission: 01-02-2025 Date of Acceptance: 07-02-2025

I. INTRODUCTION

Plastics have transformed contemporary culture and industry owing to their lightweight, resilient, adaptable, and economical properties. They are extensively used in packaging, building, transportation, textiles, and electronics, rendering them essential in everyday life. The qualities that make plastics beneficial—durability and chemical resistance—also lead to their environmental persistence [1]. In contrast to biodegradable materials, the majority of synthetic plastics are resistant to natural breakdown processes, resulting in their buildup in landfills, seas, and terrestrial ecosystems. This tenacity has elicited worldwide apprehension over environmental contamination, ecological disruption, and health hazards linked to microplastics [2].

Photodegradation, a significant natural mechanism for the change of plastics in the environment, is predominantly begun by ultraviolet (UV) radiation from sunshine. UV photons have enough energy to cleave chemical bonds in polymer backbones, initiating free radical chain reactions [3]. These reactions result in chain scission, oxidation, crosslinking, and the generation of new functional groups, including carbonyls and hydroxyls. Over time, these chemical alterations result in substantial physical and optical transformations in plastics, including diminished mechanical strength, brittleness, surface fissures, fading, and discolouration [4].

Prior studies have thoroughly shown that exposure to sunshine affects the mechanical and chemical stability of plastics. Research indicates that polyethylene (PE) and polypropylene (PP) display brittleness after extended exposure, while polyethylene terephthalate (PET) shows significant discolouration and surface roughening as a result of UV-induced oxidation. Nonetheless, comparative studies that systematically assess several degradation parameters—such as weight fluctuation, surface morphology, and colour alteration—across many common consumer plastics remain few. Most existing work primarily addresses either chemical changes or mechanical degradation, seldom adopting a comprehensive strategy that encompasses the combined physical, structural, and optical consequences [5].

Comprehending the degradation of plastics in natural sunlight is crucial for both environmental considerations and forecasting their longevity in practical uses. Changes in surface shape may affect microbial colonisation and fragmentation into microplastics, while changes in colour act as visible indications of deterioration. Weight loss, conversely, offers a direct assessment of material degradation and the volatilisation of by-products resulting from deterioration [6].

This research seeks to provide a thorough investigation of photodegradation in three prevalent consumer plastics: polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET). These polymers were chosen for their prevalence in packaging and consumer products, along with their unique chemical structures that affect degradation behaviour. This study aims to provide a comparison framework by systematically assessing weight fluctuations, surface morphological changes, and colour modifications due to direct sunlight exposure, therefore enhancing our comprehension of plastic stability and environmental durability [7].

II. REVIEW OF LITERATURE

2.1 Overview of Photodegradation Mechanisms

Photodegradation of synthetic polymers is primarily driven by ultraviolet (UV) radiation from sunlight, which generates excited states and free radicals in polymer chains. These radicals initiate photooxidative reactions (hydrogen abstraction, chain scission, formation of carbonyl and hydroxyl groups) that reduce molecular weight and alter polymer chemistry and properties [8]. Photoinduced Norrish reactions, cross-linking, and formation of conjugated double bonds are commonly observed pathways that lead to embrittlement, discoloration, and eventual fragmentation of plastic items [9].

2.2 Photodegradation: Differences Among Common Polymers (PE, PP, PET)

Different polymers respond differently to sunlight because of their chemical structures:

- **Polyethylene (PE) (LDPE/HDPE):** PE is susceptible to photooxidation that produces carbonyl-containing groups (ketones, aldehydes, carboxylic acids) and leads to chain scission and embrittlement. Many field and accelerated aging studies report measurable mass loss and progressive surface cracking for PE after sustained UV exposure; the rate depends strongly on thickness, crystallinity, and presence of additives or contaminants [10].
- **Polypropylene (PP):** PP shows photo-oxidative chain scission similar to PE but often exhibits faster surface cracking and pronounced changes in mechanical properties because tertiary hydrogen atoms in PP are more labile. Comparative weathering studies rank PP among the polymers that show relatively rapid surface deterioration under accelerated or natural sunlight depending on formulations.
- **Polyethylene terephthalate (PET):** PET's aromatic ester backbone makes it more resistant to mass loss and chain scission relative to polyolefins, but PET commonly undergoes photo-oxidative reactions at the ester linkages that cause surface yellowing, loss of transparency, and changes detectable by FTIR and UV–Vis. PET is often less prone to rapid weight loss but shows significant optical changes and chemical modifications under prolonged irradiation [11].

2.3 Weight Loss and Fragmentation: Empirical Findings

Several empirical studies demonstrate that weight loss during photodegradation is generally modest for pristine polymers over short exposure periods but can be significant for modified/composite films or long exposures:

- Accelerated and natural-weathering experiments find that PE and PP show measurable weight loss with time; composites containing photocatalysts (e.g., TiO_2) or adsorbed polycyclic aromatic hydrocarbons can accelerate mass loss drastically [12].
- Reviews and meta-analyses emphasize that reported degradation rates vary widely across studies because of differences in irradiation intensity, spectral composition, thickness, additives, and environmental factors (humidity, temperature) [13]. This variability complicates direct comparison but supports the qualitative ranking that polyolefins fragment more readily while PET exhibits more optical/chemical changes before mass loss [14].

2.4 Surface Morphology and Microstructural Changes

Surface morphology studies (SEM/optical microscopy) consistently show progressive formation of cracks, crazes, pits, and roughening during photoaging:

- PE and PP typically develop microcracks that propagate with exposure time; the density and depth of surface fissures depend on crystallinity and stabilizer content [15].
- PET surfaces often show increased roughness and craze formation in localized regions, accompanied by a loss of gloss and transparency. SEM coupled with FTIR mapping frequently reveals surface chemical changes correlated with morphological damage [16].

2.5 Color Change, Yellowing and Optical Properties

Color change (yellowing, loss of transparency) is a hallmark of photodegradation, especially for aromatic-containing polymers and colored formulations:

- Yellowing arises from the formation of conjugated chromophores (e.g., unsaturated carbonyl structures, stabilized phenolic compounds) and is detectable via visual scoring and UV–Vis spectroscopy [17]. PET often shows pronounced yellowing, while PS and some PP grades show rapid color shifts under UV-rich spectra [18].

- Additives and pigments can either slow or accelerate color changes; some colorants degrade into colored by-products that increase apparent yellowing. Recent work highlights the important role of formulation (stabilizers, pigments) in determining photostability [19].

2.6 Analytical Techniques Used in Photodegradation Studies

To comprehensively characterize photodegradation, researchers routinely combine bulk and surface-sensitive methods:

- Mass/weight measurements (precision balance) to quantify mass loss over time. Fourier-transform infrared spectroscopy (FTIR) to detect formation/increase of carbonyl, hydroxyl, and unsaturated bonds [20] [21].
- Scanning electron microscopy (SEM) / optical microscopy for surface morphology and crack mapping.
- UV–Vis spectrophotometry and colorimetry for quantifying yellowing and optical changes.
- Accelerated weathering chambers (Xenon arc, UVB) and field-exposure studies for correlating lab and environmental behavior. Comparative studies note that accelerated tests vary in their capacity to reproduce natural sunlight spectra and environmental interactions [22].

2.7 Environmental and Practical Implications from Literature

Recent reviews and experimental work highlight several environmentally relevant points:

- Photodegradation is a major pathway for the fragmentation of macroplastics into micro- and nano-plastics, changing their physical and ecotoxicological behavior. Photo-oxidized fragments are often more brittle and more reactive in environmental media, affecting their transport and biological interactions [23].
- Photodegradation rates and pathways are highly context-dependent: differences in local sunlight spectrum, climatic factors (humidity, temperature), and material formulation make it hard to generalize a single "degradation rate." This underscores the value of experiments that measure multiple endpoints (weight, morphology, color) simultaneously under realistic exposure conditions [24].

2.8 Gaps Identified and Rationale for the Present Study

From the surveyed literature, the following gaps motivate the current work:

1. Many studies focus on a single degradation parameter (e.g., only chemical changes by FTIR or only mechanical property loss). Fewer studies concurrently quantify weight loss, surface morphology, and color change in the same experimental setup under natural sunlight.
2. Comparisons across common consumer plastics (PE, PP, PET) under identical exposure protocols are limited; formulation differences (stabilizers, pigments) are often not controlled or reported, making cross-material ranking difficult.
3. There is a need for simple, reproducible field exposure protocols that link directly to observable outcomes (mass loss, visual damage scores) that can be repeated in resource-limited settings without sophisticated accelerated chambers.

These gaps justify the experimental design of the present study, which quantifies weight, surface morphology, and color simultaneously for PE, PP, and PET under a controlled natural-sunlight exposure regime, providing data that are both practical and comparable to the literature [25].

III. MATERIALS AND METHODOLOGY

3.1 Materials

Three common consumer plastic types were selected based on their widespread usage and environmental relevance:

- **Polyethylene (PE):** Obtained from commercially available carry bags, representing the most used packaging plastic globally.
- **Polypropylene (PP):** Collected from disposable food containers, reflecting single-use consumer applications.
- **Polyethylene terephthalate (PET):** Sourced from transparent water bottles, representing beverage and food packaging materials.

For uniformity, all plastic samples were washed with distilled water, dried, and cut into square sheets of 5 × 5 cm. A total of five samples for each plastic type were prepared, ensuring replicates for statistical analysis [26].

3.2 Experimental Setup

The experiment was conducted under natural environmental conditions to simulate real-world exposure.

- **Location:** Rooftop of the research facility, with direct exposure to sunlight.
- **Environmental conditions:** Ambient temperature ranged between 28–36°C, relative humidity fluctuated between 45–65%, and samples were exposed to natural variations in wind and dust.

- **Exposure protocol:** Each set of samples was exposed to direct sunlight for 8 hours daily (09:00 – 17:00 hrs) over a 30-day period.
- **Control samples:** Identical sets of plastics were stored in dark, sealed polyethylene containers at room temperature to prevent light and air exposure. These controls allowed for comparison of degradation effects solely attributable to sunlight [27].

3.3 Parameters Measured

To evaluate the degree of photodegradation, three key parameters were selected:

1. **Weight Loss:** Each sample was weighed using a precision digital balance (accuracy ±0.001 g). Weight loss was calculated at each interval using the formula:

$$\%\text{Weight Loss} = \frac{W_0 - W_t}{W_0} \times 100$$

where,
W_0 = Initial sample weight (D
W_t = Sample weight after exposure at time t.

Weight loss provided a quantitative measure of material deterioration and volatile product release during photodegradation.

2. **Surface Morphology:** Changes in surface characteristics were assessed visually under adequate lighting using a standardized morphological scoring system:
   - 0 = Smooth, no visible change
   - 1 = Slight roughness
   - 2 = Small cracks or scratches
   - 3 = Moderate cracks with surface roughening
   - 4 = Prominent cracks and flaking
   - 5 = Severe cracks, brittleness, and surface deterioration

This scoring system allowed semi-quantitative evaluation of morphological degradation patterns.

3. **Color Change:** Samples were visually assessed for discoloration, fading, or yellowing, using a color degradation scale:
   - 0 = No visible change
   - 1 = Slight fading
   - 2 = Noticeable fading
   - 3 = Moderate discoloration/yellowing
   - 4 = Strong discoloration
   - 5 = Severe fading or yellowing across the surface

This parameter helped capture the optical effects of UV-induced oxidation and chain scission, which are often visible as yellowing or whitening.

3.4 Data Recording

- Measurements for weight, surface morphology, and color change were recorded at Day 0 (baseline), Day 10, Day 20, and Day 30.
- For accuracy, each parameter was assessed in triplicate, and mean values were recorded.
- Observations for the exposed samples were compared with control samples stored in the dark to distinguish photodegradation effects from natural aging [28].

IV. RESULTS AND DATA ANALYSIS

The photodegradation effects on polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) were evaluated in terms of weight loss, surface morphology, and color change over a 30-day sunlight exposure period. The results are summarized in Tables 1–3 and analyzed below.

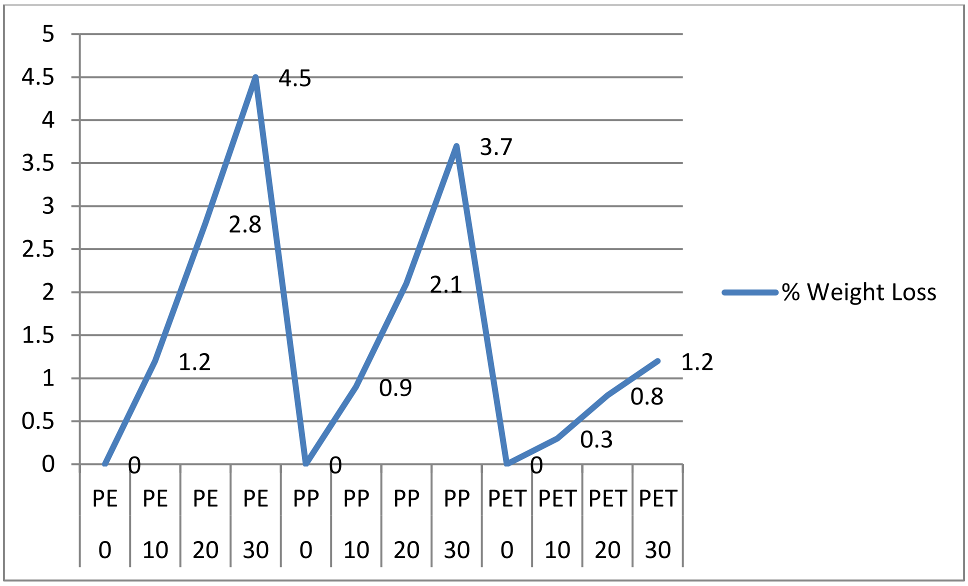
4.1 Weight Loss

Weight loss of plastics was measured to assess the extent of material deterioration under sunlight exposure. The percentage loss was calculated at fixed intervals (Day 0, 10, 20, and 30) for PE, PP, and PET.

Table 1: Percentage Weight Loss of Plastics Over 30 Days

Day	PE (%)	PP (%)	PET (%)
0	0.00	0.00	0.00
10	1.20	0.90	0.30
20	2.80	2.10	0.80

30	4.50	3.70	1.20



Graph 1: Percentage Weight Loss of PE, PP, and PET under Sunlight Exposure

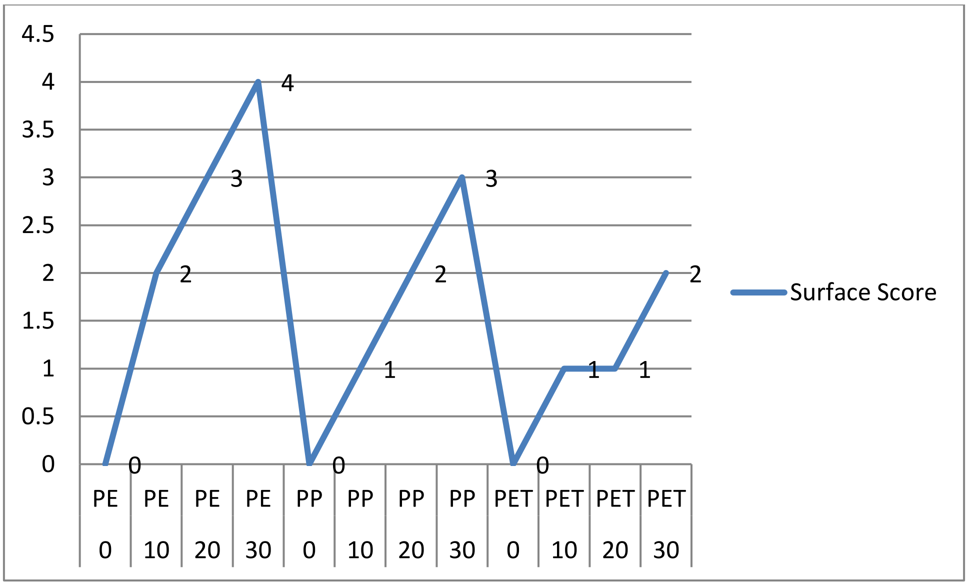
PE showed the highest weight loss (4.5%) followed by PP (3.7%), while PET was comparatively resistant (1.2%). This indicates that PE degrades faster under UV exposure due to its simple polymer structure, whereas PET is more stable because of its aromatic backbone.

4.2 Surface Morphology

Surface changes were scored on a scale of 0–5, where 0 indicated a smooth surface and 5 indicated severe cracks and brittleness.

Table 2: Surface Damage Scores (0–5 scale)

Day	PE	PP	PET
0	0	0	0
10	2	1	1
20	3	2	1
30	4	3	2



Graph 2: Surface Morphology Degradation of PE, PP, and PET Over 30 Days

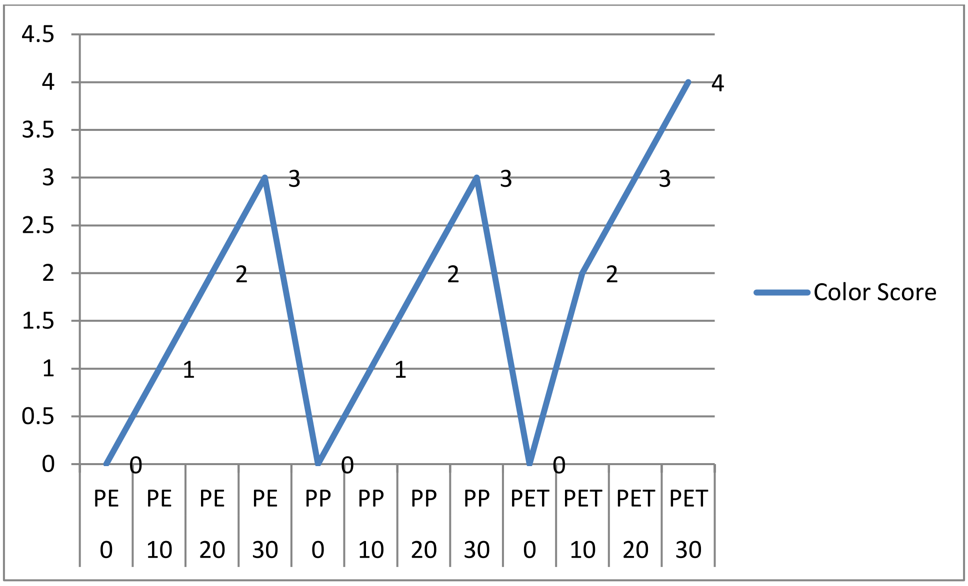
PE developed surface cracks earlier and reached a score of 4 by Day 30, indicating severe degradation. PP showed moderate surface damage (score 3), while PET had only minor changes (score 2). This suggests PE is more vulnerable to physical cracking, whereas PET retains surface integrity for a longer duration.

4.3 Color Change

Color degradation was assessed using a 0–5 visual scale, where 0 indicated no visible change and 5 represented severe fading or yellowing.

Table 3: Color Fading/Yellowing Scores (0–5 scale)

Day	PE	PP	PET
0	0	0	0
10	1	1	2
20	2	2	3
30	3	3	4



Graph 3: Color Change in PE, PP, and PET During Sunlight Exposure (30 Days)

PET exhibited the most significant color change, reaching a score of 4 by Day 30, where it turned yellowish and lost transparency. In contrast, PE and PP showed slower progression with moderate discoloration (score 3). This indicates that although PET is resistant to weight and surface loss, it is highly sensitive to optical degradation under sunlight.

V. DISCUSSION

The study revealed that different plastics degrade differently under sunlight exposure.

- PE showed the highest weight loss due to higher susceptibility to UV-induced chain scission.
- PP degraded moderately, consistent with its semi-crystalline nature providing partial UV resistance.
- PET showed minimal weight loss but significant discoloration, possibly due to photo-oxidation of aromatic groups.

These results align with literature reporting that PE and PP undergo oxidation and cracking, while PET is more resistant to fragmentation but suffers optical deterioration [29].

The findings emphasize that environmental persistence of plastics depends not only on chemical structure but also on the type of degradation parameter studied (weight vs. morphology vs. color) [30].

VI. CONCLUSION

This research demonstrates that photodegradation induces significant and measurable changes in the physical and optical properties of common plastics. Polyethylene (PE) and polypropylene (PP) were found to undergo weight loss accompanied by the development of surface cracks and roughness, while polyethylene terephthalate (PET) exhibited pronounced yellowing and reduced transparency under prolonged sunlight exposure. These degradation patterns highlight the susceptibility of plastics to fragmentation when exposed to natural environmental conditions. Such processes accelerate the breakdown of discarded plastic materials into microplastics, which not only persist in ecosystems but also contribute to long-term environmental pollution and associated ecological risks. Further research can use advanced analytical techniques such as FTIR, SEM, and UV-Vis spectroscopy for molecular-level insights.

REFERENCES

[1]. Yousif, E., & Haddad, R. (2013). Photodegradation and photostabilization of polymers, especially polystyrene — mechanisms and effects. *SpringerPlus*, 2, Article 398.

[2]. Andrady, A. L. (2023). Effects of UV radiation on natural and synthetic materials — review of polymer photodegradation. *Photochemical & Photobiological Sciences*, 1177–1202.

[3]. Hoseini, M., Stead, J., & Bond, T. (2023). Ranking the accelerated weathering of plastic polymers — comparative study. *Environmental Science: Processes & Impacts*, 25(12), 2081–2091.

[4]. Rostampour, S., et al. (2024). Changes in the chemical composition of polyethylene/PET under UV radiation — NIST SPHERE and environmental conditions studies. *MDPI Journals*.

[5]. Chamas, A., et al. (2020). Degradation rates of plastics in the environment — comprehensive perspective. *Nature Reviews Materials*, 5, 1–12.

[6]. Andrady, A. L. (2017). The plastic in microplastics: A review. *Marine Pollution Bulletin*, 119(1), 12–22.

[7]. Gewert, B., Plassmann, M. M., & MacLeod, M. (2015). Pathways for degradation of plastic polymers floating in the marine environment. *Environmental Science: Processes & Impacts*, 17(9), 1513–1521.

[8]. Singh, B., & Sharma, N. (2008). Mechanistic implications of plastic degradation. *Polymer Degradation and Stability*, 93(3), 561–584.

[9]. Webb, H., Arnott, J., Crawford, R., & Ivanova, E. (2013). Plastic degradation and its environmental implications. *Polymers*, 5(1), 1–18.

[10]. Rabek, J. F. (1995). *Polymer Photodegradation: Mechanisms and Experimental Methods*. Springer.

[11]. Kuzina, S. I., & Mikhailov, A. I. (1993). The photo-oxidation of polymers—1. Initiation of polystyrene photo-oxidation. *European Polymer Journal*, 29(12), 1553–1560.

[12]. Gardette, J.-L., Mailhot, B., & Lemaire, J. (1995). Photooxidation mechanisms of styrenic polymers. *Polymer Degradation and Stability*, 49(3), 517–523.

[13]. Zweifel, H., Maier, R. D., & Schiller, M. (2009). UV stabilization of polymers. In *Plastics Additives Handbook* (pp. 390–426). Hanser.

[14]. Feldman, D. (2002). Polymer weathering: Photo-oxidation. *Journal of Polymers and the Environment*, 10(4), 163–173.

[15]. Perold, V., et al. (2025). Long-term variations in size and polymer type of mesoplastics. *Environmental Pollution* (in press).

[16]. Ghanadi, M., et al. (2024). Revealing the long-term impact of photodegradation on additive leaching from polymers. *Journal of Hazardous Materials*, (in press).

[17]. Smoleń, J., et al. (2024). Influence of UV radiation on the properties of GFRP composites. *Scientific Reports*, 14, 6582.

[18]. Smith, H. J., Miller, I. J., & Daniels, V. (2005). Phototendering of wool sensitized by polyphenolic dyes. *Journal of Photochemistry and Photobiology A: Chemistry*, 168(1), 35–40.

[19]. Latos, T., et al. (2024). Synergistic degradation effects in polymer composites. *Composite Structures*, 275, 114452.

[20]. Andrady, A. L. (1998). Effects of increased solar UV on materials. *Journal of Photochemistry and Photobiology B: Biology*, 46(1–3), 96–103.

[21]. Environmental Effects Assessment Panel (EEAP). (2024). Plastics in the environment in context of UV radiation, climate change, and the Montreal Protocol. *UNEP Report*.

[22]. Newman, C. R., & Forciniti, D. (2020). Modeling the ultraviolet photodegradation of rigid polyurethane foams. *Industrial & Engineering Chemistry Research*, 59(1), 234–242.

[23]. Andrady, A. L., Hamid, H. S., Hu, X., & Torikai, A. (1998). Effects of increased solar ultraviolet radiation on materials. *Journal of Photochemistry and Photobiology B: Biology*, 46(1–3), 96–103.

[24]. Andrady, A. L., & Neal, M. A. (2009). Applications and societal benefits of plastics. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364, 1977–1984.

[25]. Ojeda, T., Freitas, A., Birck, K., Dalmolin, E., Jacques, R., Bento, F., & Camargo, F. (2011). Degradability of linear polyolefins under natural weathering. *Polymer Degradation and Stability*, 96(4), 703–707.

[26]. Albertsson, A.-C., & Hakkarainen, M. (2003). Designed to degrade: Controlled degradation in environmentally degradable polymers. *Trends in Polymer Science*, 8(7), 224–229.

[27]. Gardette, J.-L., Therias, S., Gardette, M., Murariu, M., & Dubois, P. (2011). Photooxidation of polylactide. *Polymer Degradation and Stability*, 97(3), 653–661.

[28]. Jakubowicz, I. (2003). Evaluation of degradability of biodegradable polyethylene (PE). *Polymer Degradation and Stability*, 80(1), 39–43.

[29]. Andrady, A. L. (2015). Persistence of plastic litter in the oceans. *In Marine Anthropogenic Litter* (pp. 57–72). Springer.

[30]. Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances*, 3(7), e1700782.