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Qualitative Studies of Selected Types of Composts

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Abstract: More and more waste is being generated in the world. One form of waste processing is the composting process. This work aims to study the morphological composition of selected composts to determine the amounts of the various fractions contained therein. In the present work, four types of composts are presented to study their morphological composition. Composted grass, backyard compost, soil improver formed after composting green waste, and stabiliser – waste formed due to mechanical-biological processing of municipal waste taken from the Municipal Waste Mechanical-Biological Treatment Facility – were studied successively. Fifty samples of 2 kilograms each were taken from each group of composts, respectively. Each sample was divided into seven fractions: organic waste, plastics, ceramics, paper and cardboard, glass, metal and others. After analysis, it can be concluded that it is very difficult to obtain homogeneous compost due to the heterogeneity of the raw material. The results are accurately presented in tables with the distinction of the different fractions. It was found that mowed grass contained the most organic matter, while stabiliser contained the least. The least amount of plastic was found in backyard compost, and the most in stabiliser.

Keywords: composting, waste, morphology, plastic, microplastic

1. Introduction
Organic waste, composting process, waste morphology

Humans have produced waste since the beginning of their existence. However, unlike natural waste produced by organisms, which provides raw material for other species, man-made waste is not part of nature's natural cycle of matter (Ayilara et al. 2020, Wagas et al. 2023, Ciuła et al. 2022). The ever-increasing production of municipal and industrial waste in recent years is primarily associated with rising living standards, progressive economic and industrial development, and increasing commercialisation in many countries around the world (Lamichhane et al. 2023, Padervand et al. 2020, Shamsuyeva et al. 2021). The increasing consumerism of society results in the mass production of waste, among which are toxic and environmentally hazardous wastes (Silva et al. 2018, Ya et al. 2021). Despite new recovery and neutralisation techniques, waste disposal by deposition in landfills is still an accepted and used method in Poland and developed countries of the European Union. This is due to both the economic aspects of landfilling and minimising the environmental impacts of waste (Kowalski et al. 2012, Kostecka et al. 2014). Composting is one form of processing and managing mainly organic waste (Jiang et al. 2023).

Organic waste includes vegetable waste in the form of leftover used fruits and vegetables, waste from the food industry, manure, waste from the textile industry, pulp and paper industry, logging industry, sludge obtained from reagent treatment of wastewater and sewage water (activated sludge), as well as dead poultry and livestock (Kumar et at. 2023, Kalali et al. 2023). Organic waste can be used as compost, but organic waste does not become compost in a landfill due to lack of oxygen; it is compacted (pushed down) and covered with a layer of soil, so it is difficult for aerobic bacteria to reach the organic matter (Mo et al. 2023). Organic waste gradually releases sulfur oxides, hydrogen sulfide and mercaptans, which have a foul odour (Agapios et al. 2020, Gaska et al. 2023). It has long been used in agriculture as one of the best organic fertilisers. Manure contains water, organic matter, total nitrogen, phosphorus and potassium oxide. Depending on the type of manure, it is applied differently to different soils. A similar study is the creation of compost based on domestic organic food waste (potato peelings, fruit and vegetable pieces, egg shells, tea waste, coffee grounds, etc. (Gronba-Chyła et al. 2024, Grąz et al. 2022, Kobylarczyk et al. 2023).

Composting is "the biological decomposition and stabilisation of organic raw materials under conditions that allow thermophilic temperatures to occur as a result of biological heat production, with a final product stable enough for storage and use for soil fertilisation without adverse effects on the environment (Generowicz et al. 2011, Grąz et al. 2023). These processes are intensified by creating optimal conditions for the metabolic transformation of microorganisms (Aylaj et al. 2023, Ciuła et al. 2024).

Compost should be stable and mature before it is managed. If the compost is stable, mineralisation processes do not occur. The compost mustn't contain small-molecule organic acids that are toxic to plants. If there are any small-molecule acids, then such compost is of poor quality and unsuitable for soil fertilisation. Mature compost should be dark brown to black, regardless of the composition of organic waste. The temperature determined under standard conditions should not exceed 30°C, while the smell should be very similar to that of forest mulch (Shean et al. 2022). The compost should be free of plastics, metals and hard materials, especially pieces of glass and ceramics, which can lead to cuts (Gronba-Chyła et al. 2021, Kumar et al. 2023). To be considered safe, it must have a low content of heavy metals and toxic organic compounds, a low concentration of soluble salts, no pathogens for humans or animals, and no weed seeds either (Mateos-Caedenas et al. 2021, Gronba-Chyła 2023).

Composting has been an increasingly popular method of recovering biodegradable waste for several years (Grąz et al. 2023). However, for the transformation and stabilisation process to proceed properly and for the compost itself to be considered a final product of good quality, care must be taken to ensure the proper selection of installations and to maintain the proper parameters of the process itself (Timilsina et al. 2023). Composting is one type of recovery, i.e., a process whose main result is that waste serves a useful purpose by replacing other materials that would otherwise be used to fulfil a function, or as a result of which waste is prepared to fulfill such a function in a given facility or in the economy in general (Gronba-Chyła et al. 2020, Augustowski et al. 2020).

The composting process takes place in four sequential phases: mesophilic, thermophilic, cooling and maturation. Considering the selection of industrial installations, one should be guided by their adaptation to the process transformations occurring during the first three phases (Shen et al. 2019, Wang et al. 2021, Ciuła et al. 2022). However, during the maturation phase, which is the longest of the phases, the stabilisation of the compost and the formation of humus substances occur (Grąz et al. 2023, Ciuła et al. 2024, Gronba-Chyła et al. 2022). Therefore, the installation itself has little influence on its progress, and maturation time seems to be a far more important factor. Compost production from various waste materials or manure requires a location or site suitable for local regulations and appropriate for the composting process. A central location should be chosen to reduce transportation costs, but it must be away from residential areas to reduce potential odour, noise or insect problems (Zhao et al. 2022, Kwaśnicki et al. 2023, Varghese et al. 2023).

Morphological analysis, or determination of the group composition of waste, is considered the most important source of information about municipal waste. It is aimed at separating different waste groups, such as plastics, paper, glass, wood, metals, etc. The information obtained from the study of the morphological composition of waste allows the organising a better waste management system and influences the selection of an appropriate waste treatment system (Shen et al. 2022, Braun et al. 2023, Roshanzadeh et al. 2021, Ciuła et al. 2018). The same is true for the morphological analysis of composts.

2. Materials and Methods

This paper presents a study of the morphology of organic composts. The analysis of compost samples was carried out following the PN-93-Z-15006 standard. Four types of composts were tested:

- composted grass, previously mowed, taken from a property in a rural area located in the Subcarpathian region,
- backyard compost, taken from a property in a small village in the Subcarpathian region,
- soil improver – compost created after composting green waste taken from the Municipal Waste Mechanical and Biological Treatment Plant,
- stabiliser – waste generated from the mechanical-biological treatment of municipal waste taken from a medium-sized city's Municipal Waste Mechanical-Biological Treatment Plant.

The tests were conducted during the summer months, from June to July.

From each group of composts, 50 samples were taken respectively, 2 kilograms each. The compost samples were handled the same way as the study of the morphology of municipal waste following the PN-93-Z-15006 standard. Each collected compost sample was sieved through a sieve with a mesh size of 80 mm, on a laboratory shaker.

The samples were then separated into 7 fractions: organic waste, plastics, ceramics, paper and cardboard, glass, metal and other components. Each sample was accurately weighed on a laboratory scale. The results are presented in the tables below (Table 1, Table 2, Table 3, Table 4).

3. Results and Discussion

Analysing the results obtained from the individual fractions (organic waste, plastics, ceramics, paper and cardboard, glass, metal and others) of the different types of composts and comparing them with each other, one can draw a simple conclusion that the chosen method of sample preparation was suitable for this type of study. You can see very large discrepancies in the average values of individual fractions in different composts. There is no doubt that the samples were heterogeneous, and there are large weight differences in individual fractions within the four types of materials tested – composts.

3.1. Mowed and composted grass

Table 1 shows a study of the morphology of mowed and composted grass taken from the property of a rural community located in the Subcarpathian region. Fifty samples of 2000 grams each were taken, that is, 100 kilograms of composted grass.

Table 1. Composted grass

	Organic waste	Plastics	Ceramics	Paper & cardboard	Glass	Metal	Other
Average sample weight	1959.16 g	10.83 g	25.85 g	0.48 g	0.61 g	2.32 g	0.76 g
Standard deviation	64.1	23.35	64	1.52	2.22	12.61	2.66
Coefficient of variation	3%	216%	248%	317%	364%	544%	350%

The following weight averages were extracted: organic waste weighed an average of 1959.16 grams, and plastics accounted for an average of 10.83 grams of the sample. Ceramics weighed an average of 25.85 g. An average of 0.48 g of paper and cardboard was extracted, while glass accounted for an average of 0.61 g. Metal found in the samples examined weighed an average of 2.32 g. Other residues that did not belong to any of the previously listed fractions weighed an average of 0.76 g.

The standard deviation and coefficient of variation were highly divergent within the samples. The coefficient of variation for organic waste weight accounted for 3% of the sample difference. The greatest variability was in the measurement of the metal content of the samples, a difference of 544%, which represents very heterogeneous samples in terms of the content of this component. This indicates that in some samples, the metal content was not recorded. Next, for the next fraction, that is, glass, the coefficient of variation was also high – 364%, indicating that glass was not present in all of the 50 samples taken. The same was true for ceramics, with a coefficient of variation of 248%, indicating a lack of homogeneity in terms of ceramic content. For example, some samples contained decorative pebbles from beds next to lawns. Likewise, there were large differences in the content of plastics in the samples, the coefficient of variation was 216%. The isolated plastics were mainly plastic items, which were the line residue from the pruner used to trim the lawn.

3.2. Backyard compost

Table 2 shows a study of the morphology of samples from a backyard composter located on a plot next to a single-family home, a family of 4, in a rural community. Fifty samples of 2000 g each were taken, that is, 100 kilograms of compost from the backyard composter.

Table 2. Backyard compost

	Organic waste	Plastics	Ceramics	Paper & cardboard	Glass	Metal	Other
Average sample weight	1995.68 g	0.17 g	0.44 g	3.7 g	0 g	0 g	0 g
Standard deviation	15.67	0.51	1.7	15.52	0	0	0
Coefficient of variation	1%	283%	370%	419%	0%	0%	0%

The following weight averages were extracted: organic waste weighed an average of 1995.68 g, which was mainly visibly vegetable and fruit peelings and food scraps. Plastics accounted for an average of 0.17 g of the sample tested, mainly fruit and vegetable stickers. Ceramics weighed an average of 0.44 g. An average of 3.7 g of paper and cardboard was extracted mainly eggshell residue. Glass, metal, and the so-called other fractions were not detected, which indicates thorough segregation and meticulousness when introducing the material into the composter. The coefficient of variation for the weight of organic waste accounted for 1% of the sample difference, confirming the thorough segregation of the input material into the process.

The biggest variation was in the measurement of the paper and cardboard content of the samples, a difference of 419%, which is a very heterogeneous sample in terms of the content of this component. The owner is perhaps deliberately introducing eggshells to improve the composting process.

Next, for the next fraction, that is, ceramics, the coefficient of variation was also high – 370%, indicating that ceramics were present in not all of the 50 samples taken and that traces of ceramics may have appeared from a one-time breakage of a dish at home, the remains of which, with peelings, ended up on the compost heap. The same was true of plastics, with a coefficient of variation of 283%, indicating a lack of homogeneity in terms of the content of plastics or even microplastics in the sample. In some samples, there were occasional visible fruit or vegetable stickers stuck to the peels by the producers, which, along with the peelings, ended up on the composter.

3.3. Soil improver – green waste composting

Table 3 shows the study of the morphology of organic samples from green waste of the so-called soil improver from the Municipal Mechanical and Biological Waste Treatment Plant of the municipality. Fifty samples of 2,000 grams each were taken, that is, 100 kilograms of material.

Table 3. Soil improver – composting green waste

	Organic waste	Plastics	Ceramics	Paper & cardboard	Glass	Metal	Other
Average sample weight	1935.79 g	12.04 g	30.26 g	0.82 g	0.21 g	2.69 g	0.8 g
Standard deviation	70.31	19.16	67.09	2.24	0.6	13.03	3.10
Coefficient of variation	4%	159%	222%	273%	286%	484%	388%

The following weight averages were extracted: organic waste weighed an average of 1935.79 g, and plastics accounted for an average of 12.04 g of the sample. Ceramics weighed an average of 30.26 g. An average of 0.82 g of paper and cardboard was extracted, and glass accounted for an average of 0.21 g. Metal found in the samples examined weighed an average of 2.69 g. Other residues that did not belong to the previously listed fractions weighed an average of 0.8 g. The standard deviation and the coefficient of variation were highly divergent within the samples. The coefficient of variation for the weight of organic waste accounted for 4% of the sample difference. The highest variability was in the measurements of metal content in the samples, a difference of 484%, which represents very heterogeneous samples in terms of the content of this component. This indicates that in some samples, the metal content was not recorded. Next, for the next fraction, that is, glass, the coefficient of variation was also high – 286%, indicating that glass was not present in all of the 50 samples taken. The same was true for ceramics, with a coefficient of variation of 222%, indicating a lack of homogeneity in terms of ceramic content.

3.4. Stabiliser

Table 4 shows the study of the morphology of stabiliser samples – waste code 19 05 99 resulting from composting of municipal waste from the Municipal Mechanical and Biological Treatment Plant. Fifty samples of 2000 grams each were taken, that is, 100 kilograms of material.

Table 4. Stabiliser

	Organic waste	Plastics	Ceramics	Paper & cardboard	Glass	Metal	Other
Average sample weight	706.8 g	1234.39 g	43.8 g	5.07 g	5.28 g	2.86 g	1.8 g
Standard deviation	234.83	233.31	75.04	8.14	7.63	5	3.92
Coefficient of variation	33%	19%	171%	161%	145%	175%	218%

The following weight averages were extracted: organic waste weighed an average of 706.8 g, and plastics accounted for an average of 1234.39 g of the sample tested. Ceramics weighed an average of 43.8 g. An average of 5.07 g of paper and cardboard was extracted, while glass accounted for an average of 5.28 g. Metal found in the samples examined weighed an average of 2.86 g. Other residues that did not belong to any of the previously listed components weighed an average of 1.8 g. Both the standard deviation and coefficient of variation varied widely within the samples. The coefficient of variation for the weight of organic waste accounted for

33% of the sample difference. The greatest variability was in the measurements of the content of "other" components in the samples, a difference of 218%, representing very heterogeneous samples in terms of the content of these unspecified components. Next, for the next fraction, that is, glass, the coefficient of variation was also high – 145%, indicating that glass was present in not all of the 50 samples taken. The same was true for ceramics, with a coefficient of variation of 171%, which also indicates a lack of homogeneity in terms of the content of ceramic materials. As for the weight of plastic materials found in the samples taken, the coefficient of variation was only 19%, indicating that plastics were present in every sample, with slight differences in their total weight.

4. Conclusion

1. Composting is a time-consuming process, and it is very difficult to obtain a uniform compost due to the heterogeneity in the input material.
2. The aim of the study was achieved – as a result of the analysis following the PN-93-Z-15006 standard, it was possible to select individual fractions (organic waste, plastics, ceramics, paper and cardboard, glass, metal and others) in the selected 4 composts, that is: composted grass, backyard compost, soil improver and stabiliser.
3. It was found that the individual samples are very heterogeneous. There is a very large discrepancy in the weight of the different fractions separated in the analysed composts.
4. This research will continue to select suitable compost for soil improvement.
5. The most organic matter was found in mowed composted grass at an average of 1959.16 g per 2000 g sample, and the least in stabiliser – 706.8 g from 2000 g sample.
6. The least amount of plastic was in the backyard compost, i.e. 0.17 g, which is only 0.0085% of the sample, and the most was in the stabiliser, i.e. 1234.39 g from 2000 g, about 62% of the sample.

References

Agapios, A., Andreas, V., Marinos, S., Katerina, M., Antonis, Z.A. (2020). Waste aroma profile in the framework of food waste management through household composting. *Journal of Cleaner Production*, *257*, 120340. ISSN 0959-6526. https://doi.org/10.1016/j.jclepro.2020.120340

Augustowski, D., Kwaśnicki, P., Dziedzic, J., Rysz, J. (2020). Magnetron sputtered electron blocking layer as an efficient method to improve dye-sensitised solar cell performance. *Energies*, *13*(11), 2690.

Ayilara, M.S., Olanrewaju, O.S., Babalola, O.O., Odeyemi, O. (2020). Waste management through composting: Challenges and potentials. *Sustainability*, *12*(11), 4456.

Aylaj, M, Adani, F. (2023). The Evolution of Compost Phytotoxicity during Municipal Waste and Poultry Manure Composting. *Journal of Ecological Engineering*, *24*(6), 281-293. https://doi.org/10.12911/22998993/161822

Braun, M., Mail, M., Krupp, A.E., Amelung, W. (2023). Microplastic contamination of soil: Are input pathways by compost overridden by littering? *Science of The Total Environment*, *855*, 158889, ISSN 0048-9697. https://doi.org/10.1016/j.scitotenv.2022.158889

Ciuła, J., Gaska, K., Generowicz, A., Hajduga, G. (2018). *Energy from landfill gas as an example of circular economy*, E3S Web of Conferences, Vol. 30, The First Conference of the International Water Association IWA for Young Scientist in Poland "Water, Wastewater and Energy in Smart Cities", Cracow, Poland. https://doi.org/10.1051/e3sconf/20183003002

Ciuła, J., Generowicz, A., Gronba-Chyła, A., Kwaśnicki, P., Makara, A., Kowalski, Z., Wiewiórska, I. (2024). Energy production from landfill gas, emissions and pollution indicators-opportunities and barriers to implementing circular economy. *Energy*, *308*, 132951. https://doi.org/10.1016/j.energy.2024.132951

Ciuła, J., Generowicz, A., Wiewiórska, I., Gaska, K., Gronba-Chyła, A., Golonka, M., Makara, A. (2024). Environmental aspect of waste to energy installation: quality of waste generated by technology. *Clean Technologies and Environmental Policy*, 1-16. https://doi.org/10.1007/s10098-024-02788-0

Ciuła, J., Generowicz, A., Gaska, K., Gronba-Chyła, A. (2022). Efficiency analysis of the generation of energy in a biogas CHP system and its management in a waste landfill. Case study. *Journal of Ecological Engineering*, *23*(7), 143-157, ISSN 2299-8993. https://doi.org/10.12911/22998993/149609

Gaska, K., Generowicz, A., Gronba-Chyła, A., Ciuła, J., Wiewiórska, I., Kwaśnicki, P., Chyła, K. (2023). Artificial Intelligence Methods for Analysis and Optimisation of CHP Cogeneration Units Based on Landfill Biogas as a Progress in Improving Energy Efficiency and Limiting Climate Change. *Energies*, *16*(15), 5732. https://doi.org/10.3390/en16155732

Generowicz, A., Kowalski, Z., Kulczycka, J., Banach, M. (2011). Ocena rozwiązań technologicznych w gospodarce odpadami komunalnymi z wykorzystaniem wskaźników jakości technologicznej i analizy wielokryterialnej. *Przemysł Chemiczny*, *90*(5), 747-753. ISSN 0033-2496

Grąz, K., Gronba-Chyła, A., Chyła, K. (2023). Microplastics found in compost as a barrier to the circular economy (CE). *Przemysł chemiczny*, *102*(4), 381-383. https://doi.org/10.15199/62.2023.4.7

Grąz, K., Generowicz, A., Kwaśny, J. (2022). Nanoparticles in surface water. *Przemysł Chemiczny*, *101*(1). (in Polish). https://doi.org/10.15199/62.2022.1.8

Grąz, K., Generowicz, A., Kwaśny, J., Gronba-Chyła, A., Kwaśnicki, P., Ciuła, J., Bajdur, W. (2023). Microplastics from Plastic Waste as a Limitation of Sustainability of the Environment. *Rocznik Ochrona Środowiska*, *25*. https://doi.org/10.54740/ros.2023.037

Gronba-Chyła, A., Generowicz, A., Kwaśnicki, P., Cycoń D., Kwaśny, J., Grąz, K., Gąska, K., Ciuła, J. (2022). Determining the Effectiveness of Street Cleaning with the Use of Decision Analysis and Research on the Reduction in Chloride in Waste. *Energies*, *15*, 3538. https://doi.org/10.3390/en15103538

Gronba-Chyła, A. (2023). Experimental investigation on the properties of street and sidewalk cleaning waste*, Architecture, Civil Engineering, Environment*, *16*(4), 149-153. https://doi.org/10.2478/acee-2023-0058

Gronba-Chyła, A. Generowicz, A. Kramek (2021). Using selected types of waste to produce new light ceramic material. *Pol. J. Environ. Stud.*, *30*(3), 2073-2083. https://doi.org/10.15244/pjoes/126496

Gronba-Chyła, A., Generowicz, A. (2020). Frakcja odpadów komunalnych poniżej 10 mm i możliwość jej wykorzystania w ceramicznych materiałach budowlanych. *Przemysł Chemiczny*, *99*(9), 1000-1003. (in Polish). https://doi.org/10.15199/62.2020.9.10

Gronba-Chyła, A., Generowicz, A., Alwaeli, M., Mannheim, V., Grąz, K., Kwaśnicki, P., Kramek, A. (2024). Municipal waste utilisation as a substitute for natural aggregate in the light of the circular economy. *Journal of Cleaner Production*, *440*, 140907. https://doi.org/10.1016/j.cej.2021.131928

Jiang, P., Zhang, L., You, S., Van Fan, Y., Tan, R.R., Klemeš, J.J., You, F. (2023). Blockchain technology applications in waste management: Overview, challenges and opportunities. *Journal of Cleaner Production*, *421*, 138466. https://doi.org/10.1016/j.jclepro.2023.138466

Kalali, E.N., Lotfian, S., Shabestari, M.E., Khayatzadeh, S., Zhao, C., Nezhad, H.Y. (2023). A critical review of the current progress of plastic waste recycling technology in structural materials. *Current Opinion in Green and Sustainable Chemistry*, *40*, 100763. ISSN 2452-2236. https://doi.org/10.1016/j.cogsc.2023.100763

Kobylarczyk, J., Kuśnierz-Krupa, D., Nowak-Ocłoń, M. (2023). Impact of paving surface material on thermal conditions within a residential building. *Archives of thermodynamics*, *44*(4), 141-155. https://doi.org/10.24425/ather.2023.149709

Koctecka, J., Koc-Jurczyk, J., Brudzisz, K. (2014). Waste management in Poland and European Union. *Archiwum Gospodarki Odpadami i Ochrony Środowiska*, *16*(1), 1-10. (in Polish)

Kowalski, Z., Generowicz, A., Makara, A. (2012). Evaluation of municipal waste disposal technologies by BATNEEC. *Przemysł Chemiczny*, *91*(5). (in Polish)

Kumar, M., Ambika, S., Hassani, A., Nidheesh, P.V. (2023). Waste to catalyst: role of agricultural waste in water and wastewater treatment. *Science of The Total Environment*, *858*, 159762. https://doi.org/10.1016/j.scitotenv.2022.159762

Kwaśnicki, P., Gronba-Chyła, A., Generowicz, A., Ciuła, J., Wiewiórska, I., Gaska, K. (2023). Alternative method of making electrical connections in the 1st and 3rd generation modules as an effective way to improve module efficiency and reduce production costs. *Archives of Thermodynamics*, *44*(3), 179-200. https://doi.org/10.24425/ather.2023.147543

Lamichhane, G., Acharya, A., Marahatha, R. et al. (2023). Microplastics in environment: global concern, challenges, and controlling measures*. Int. J. Environ. Sci. Technol.*, *20*, 4673-4694. https://doi.org/10.1007/s13762-022-04261-1

Mateos-Cardenas A., van Pelt, F.N.A.M., O'Halloran, J., Jansen, M.A.K. (2021). Adsorption, uptake and toxicity of micro- and nanoplastics: Effects on terrestrial plants and aquatic macrophytes. *Environmental Pollution*, *284*, 117183, 1-10. https://doi.org/10.1016/j.envpol.2021.117183

Mo, J., Xin, L., Zhao, C., Qin, Y., Nan, Q., Mei, Q., Wu, W. (2023). Reducing nitrogen loss during kitchen waste composting using a bioaugmented mechanical process with low pH and enhanced ammonia assimilation. *Bioresource Technology*, *372*, 128664. ISSN 0960-8524.

Padervand, M., Lichtfouse, E., Robert D. et al. (2020). Removal of microplastics from the environment. A review. *Environ Chem Lett*, *18*, 807-828. https://doi.org/10.1007/s10311-020-00983-1

Roshanzadeh, A., Oyunbaatar, N.-E., Ehteshamzadeh, Ganjbakhsh, S., Park, S., Kim, D.-S., Kanade, P.P., Lee, S., Lee, D-W., Kim, E-S. (2021). Exposure to nanoplastics impairs collective contractility of neonatal cardiomyocytes under electrical synchronisation. *Biomaterials*, *278*, 121175, 1-16. https://doi.org/10.1016/j.biomaterials.2021.121175

Shamsuyeva, M., Endres, H-J. (2021). Plastics in the context of the circular economy and sustainable plastics recycling: Comprehensive review on research development, standardisation and market. *Composites Part C: Open Access*, *6*, 100168, 1-16. https://doi.org/10.1016/j.jcomc.2021.100168

Shen, M., Zhang, Y., Zhu, Y., Song, B., Zeng, G., Hu, D., Wen, X., Ren, X. (2019). Recent advances in toxicological research of nanoplastics in the environment: A review. *Environmental Pollution*, *252*, 511-521. https://doi.org/10.1016/j.envpol.2019.05.102

Shen, M., Xiong, W., Song, B., Zhou, C., Almatrafi, E., Zeng, G., Zhang, Y. (2022). Microplastics in landfill and leachate: Occurrence, environmental behavior and removal strategies. *Chemosphere*, *305*, 135325. https://doi.org/10.1016/j.chemosphere.2022.135325

Silva, A.B., Bastos, A.S., Justino, C.I., da Costa,, J.P., Duarte, A.C., Rocha-Santos, T.A. (2018). Microplastics in the environment: Challenges in analytical chemistry – A review. *Analytica chimica acta*, *1017*, 1-19. https://doi.org/10.1016/j.aca.2018.02.043

Timilsina, A., Adhikari, K., Yadav, A.K., Josh, P., Ramena, G., Bohara, K. (2023). Effects of microplastics and nanoplastics in shrimp: Mechanisms of plastic particle and contaminant distribution and subsequent effects after uptake. *Science of the Total Environment*, *894*, 164999. https://doi.org/10.1016/j.scitotenv.2023.164999

Varghese, S.A., Pulikkalparambil, H., Promhuad, K., Srisa, A., Laorenza, Y., Jarupan, L., Nampitch, T., Chonhenchob, V. (2023). Harnkarnsujarit N. Renovation of Agro-Waste for Sustainable Food Packaging: A Review. *Polymers*, *15*, 648. https://doi.org/10.3390/polym15030648

Wang, Z., Saade, N.K., Ariya, P.A. (2021). Advances in Ultra-Trace Analytical Capability for Micro/Nanoplastics and Water – Soluble Polymers in the Environment: Fresh Falling Urban Snow. *Environmental Pollution*, *276*, 116698, 1-13. https://doi.org/10.1016/j.envpol.2021.116698

Waqas, M., Hashim, S., Humphrie, U.W., Ahmad, S., Noor, R., Shoaib, M., Naseem, A., Hlain, P.T., Lin, H.A. (2023). Composting Processes for Agricultural Waste Management: A Comprehensive Review. *Processes*, *11*, 731. https://doi.org/10.3390/pr11030731

Ya, H., Jiang, B., Xing, Y., Zhang, T., Lv, M., Wang, X. (2021). Recent advances on ecological effects of microplastics on soil environment. *Science of the total environment*, *798*, 149338, https://doi.org/10.1016/j.scitotenv.2021.149338

Zhao, X., Korey, M., Li, K., Copenhaver, K., Tekinalp, H., Celik, S., Ozcan, S. (2022). Plastic waste upcycling toward a circular economy. *Chemical Engineering Journal*, *428*, 131928. ISSN 1385-8947. https://doi.org/10.1016/j.cej.2021.131928