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Accessing the Composting Potential and Phytotoxicity of Acetate Waste-Market Implications and Legal Compliance

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ABSTRACT

The study investigates the properties and waste management potential of cellulose acetate waste, commonly used in cigarette filter production. The goal of the research is to address gaps in the state of the art by assessing compostability and phytotoxicity of acetate waste from cigarettes production, which significantly complement the current research focused on cigarette filters in the form of post-consumer buts. Under investigation was acetate in the form of homogenic, dye-free and non-contaminated tow from the beginning phase of the cigarette's filters production process. The experimental framework adheres to the PN-EN 14045:2005 standard for controlled composting environments. Acute phytotoxicity assessment follows the PHYTOTESTKIT method based on PN-EN 11269-1:2013-06. Results indicate that under controlled conditions, acetate waste achieves a decomposition rate of 75.3% after 84 days. Phytotoxicity testing reveals varying germination rates for different plant species. Across substrates, only 81 out of 210 seeds germinated (39%). Specifically, green cucumber seeds showed no germination, oat seeds had a 29% germination rate (20% for compost with acetate), and cress seeds had a high 90% germination rate for each substrate. Overall, understanding these properties informs sustainable waste management practices, including potential applications in industries like geotextiles, crop mulching mats etc. The results led to the conclusion that additional testing should be perform according to the requirements specific for each industrial usage and to increase the compostability level under laboratory and natural conditions.

Keywords: waste management, European Green Deal, biodegradability, polymer, biodegradable plastic.

INTRODUCTION

The advancement of scientific knowledge has historically catalysed technological progress, which subsequently initiated growth of the economic development. This paradigm was exemplified by the invention of polymer materials at the turn of the 19th and 20th century. This breakthrough has profoundly transformed the contemporary landscape, offering a range of applications across various domains of human living—from mundane consumer goods to sophisticated medical devices and even astronomical equipment [Fisher et al., 2008; Gupta et al., 2019]. However, related with this remarkable innovation that has enhanced global living standards, there has emerged a formidable challenge: the effective management of plastic waste [Wang et al. 2021]. The growing volume of waste, especially plastic waste, is one of the components of the environmental crisis facing the world today. Enormous islands of waste in the oceans, illegal landfills, uncontrolled incineration, all this has made the topic of plastic waste management a priority not only for legislators, but also for scientists. Facing the problem of environmental pollution from plastic waste, and consequently microplastics, requires legislative changes, extensive education, and, perhaps most importantly, large-scale industrial waste management solutions and changes in plastics technologies themselves [Narancic and O'Connor, 2018].

The study by Geyer [Geyer et al., 2017] is a significant research work that presents the first global analysis of the production, use, and fate of all plastics ever made. According to those studies, the approximate virgin plastic production, by 2017, was 8.3 billion metric tons. Since plastic is widely use as packaging materials and single use materials, 6,3 billion tons from this amount already became a waste. Yearly plastic production increased from 2 million tonnes in 1950 to 460 million tonnes in 2019 [OECD, 2022]. Should the present trajectory of plastic production and usage persist, it is projected that by the year 2050, the annual worldwide output of plastic will surge to 590 million tons [Geyer et al., 2017].

Escalating apprehensions regarding the utilization of petroleum and natural gas as precursors for plastic synthesis, coupled with the ecological ramifications of traditional plastic refuse, have led scientist and industrial sector to put the effort into looking for more ecologically viable substitutes and advances waste management technologies. Bioplastics, defined as polymers that are either derived from biological sources, capable of biodegradation, or both, are fabricated employing renewable bioresources such as maize starch, plant lipids, wood particulates, cereal straws, and other similar materials. Bioplastic production not only reduces the usage of petroleum sources but also became a sustainable alternative to manage the waste from foresting and farming. A per global bioplastic production statistics, biopolymers constitute approximately one percent of the total worldwide polymer production volume [Statista, 2024]. This proportion is anticipated to escalate as bioplastics undergo further refinement and diversification in their applications. As per the data from 2022 [Statista, 2024], the global production capacity for bioplastics stood at 2.2 million metric tonnes, with projections indicating a continuous annual increase, reaching an estimated 7.4 million metric tonnes by the year 2028.

The packaging industry is the main recipient of biodegradable plastics, with a share of nearly 60% market value. According to the Allied Market Research Report [2022], the biodegradable plastics market is growing, predicting that its market value will increase several times by 2026. The global bioplastic market is dominated by Asian countries, nevertheless it is projected that also European market value will increase. At the 16th EUBP Conference, European Bioplastics presented a forecast according to which global bioplastic production is projected to growth more than triple since 2026 [Nova-Institute, 2021].

As one of the technologies that can help manage plastic waste: polymer composting is emerging as a key technique for mitigating the harmful effects of synthetic materials on ecosystems. This paper delves into the intricacies of polymer composting and its consequential phytotoxicity, with a particular emphasis on the acetate derived from cigarette filters production.

Cellulose acetate, a predominant component of cigarette filters, is a synthetic polymer that is resistant to rapid biodegradation. The continual build-up of cigarette ends, primarily consisting of cellulose acetate, represents a considerable environmental hazard. Their enduring nature and the likelihood of releasing harmful substances into ecosystems underscore the urgency of addressing this issue [Robertson et al., 2012]. As per Robertson research: The transformation of cellulose acetate in cigarette filters to cellulose and acetic acid is a critical, slow process under natural environmental conditions. Nonetheless, innovative developments in the field of controlled-release acid catalysis are offering new ways to quicken this hydrolysis, effectively improving the rate at which this degradation occurs [Robertson et al., 2012]. The breakdown of cellulose acetate within composting settings is a multifaceted process, affected by a range of living organisms and environmental conditions. Recent research has highlighted the ecotoxic effects of the substances that leach from cellulose acetate, which have the capacity to hinder plant development and the fertility of soil [Novotny and Hamzai, 2023].

The concept of phytotoxicity, which refers to the detrimental impacts of chemicals on vegetation, is an essential aspect in evaluating compost quality and its appropriateness for use in agriculture. The incorporation of cellulose acetate from discarded cigarette filters into compost has been linked to harmful phytotoxic consequences, notably in terms of the germination of seeds and the robustness of plants [Bandini et al., 2020]. This situation calls for a thorough review of composting methods and the creation of strategies to lessen the phytotoxic effects.

Building upon existing knowledge and recent studies, the researchers have undertaken composting experiments on acetate waste derived from cigarette filter production, which remains uncontaminated by consumers. This investigation aims to assess the characteristics and capabilities of acetate waste, alongside its phytotoxic effects, thereby addressing the existing knowledge deficit regarding the disposal of cigarette filter materials.

MATERIAL AND METHODS

The object of the study was cellulose acetate waste which is commonly used in tobacco industry for cigarettes filters production.

The production process for cigarette filters uses acetate in the form of a tow, which resembles cosmetic cotton wool or bedding fillings in its structure. The acetate tow (presented on Fig. 1) is soft, flexible, easy to form, fibre separation is possible, and it is colour dye-free, as white acetate tow is used. During the production process, acetate is enriched with a plasticiser to increase its stiffness and to form it into the desired cylinder shape.

The fabrication of cigarette filters constitutes a multi-stage operation necessitating sophisticated technologies and a variety of machinery to transform acetate tow into the end product: the filter. The internal properties of the material and the extensive nature of the process predominantly contribute to the generation of diverse waste streams. An acetate enriched with plasticizer, from the waste stream generated at the beginning of the production process, was used as a primary material for the composting test. In its physical and chemical characteristic waste acetate from this waste stream are homogenic, pollution-free and doesn't contain paper wrapper.

Composting test

The experimental framework adhered to the PN-EN 14045:2005 standard, which delineates the assessment criteria for the decomposition process of packaging materials in practical, controlled composting environments.

- The base material used (compost) met the requirements of the above standard in terms of nitrogen, carbon, pH value and carbon to nitrogen ratio, therefore there was no need to correct the content of these substances in the compost with external additives.
- Composting of the tested material was carried out in two repetitions.
- A total of 3 composting attempts were made:
  1. In the first attempt, no process was observed, as a result of which it was decided to add a composting booster in the form of a microbial slurry and a macroelement additive; additionally, the process was temperature-supported by heating the bioreactors. The measurement was discontinued after 35 days due to the lack of results.
  2. The second measurement lasted 42 days, also without results.
  3. In the third attempt, the composting process began. The process required regular temperature and humidity control, as well as aeration. In the first, most effective phase of the process, the samples were aerated 3 times a week, maintaining an air flow of 30 L/min for 15–20 min. On a weekly basis, the material was mixed, and water was added to maintain the humidity at 50%. After 4 weeks, the frequency of aeration was reduced to 2 times a week, while maintaining the weekly cycle of mixing and replenishing water. After 8 weeks, the frequency of aeration was reduced to once a week and a weekly mixing and humidification cycle was maintained. After 12 weeks, the material was sieved, and due to the visible elements of the undecomposed sample in the over-sieve fraction, they were separated. The elements of biomass, soil, sand and other elements of the base material used were washed out from the obtained material with the utmost care. The purified material was dried based on the difference in the mass of the input material and obtained after the process, the degree of decomposition was determined.
- All tests were performed in two repetitions with the utmost care.
- Preparation of results: expanded uncertainty determined for the coverage factor k=2 at the confidence level p=95%, does not include the sampling component.
- Sampling was provided by tobacco factory, conducted by qualified laboratory engineer.

Figure 1. Acetate tow from cigarette filters production (author's photo, scale 1:1)

- Sampling preparation and laboratory tests conducted by accredited laboratory according to PN-EN 14045:2005 Standard requirements.
- Decomposition rate [D], was calculated as:

$$D = [(M_i - M_r)/M_i] \times 100 \quad (1)$$

where: M_i stands for the initial dry mass of the acetate material and M_r represents the dry mass of the recovered acetate pieces after composting and sieving.

Phytotoxicity test

Assessment of acute phytotoxicity performed in accordance with the PHYTOTESTKIT method based on the PN-EN 11269-1:2013-06 standard.

- The test was carried out for oat, cress, and cucumber seeds (cucumber seeds did not germinate on the tested sample or on the control sample).
- The tests were performed each time in 3 replicates for both 100% green waste compost samples and green waste compost mixed with acetate waste compost.
- Soil substrate without compost was used as a control sample.
- In each repetition, 10 seeds were sown.
- Sampling preparation and laboratory tests conducted by accredited laboratory according to PN-EN 11269-1:2013-06 Standard requirements.

RESULTS AND DISCUSSION

Composting is the controlled, aerobic (oxygen-required) biological decomposition of organic materials, which is a traditional method of treating organic waste [Yin et al., 2024]. Composting, as a waste management process, is gaining attention for managing plastic waste. When it comes to biodegradable plastics, composting can indeed occur. However, research indicates that achieving effective decomposition requires specific conditions and sufficient processing time. These factors significantly influence the final degree of breakdown [Nizamuddin and Chen, 2024].

Acetate is one of the plastic types, produced from cellulose, which is natural product wildly present in agriculture waste. Cellulose is a polysaccharide that is found in the plant cell walls. Cellulose structure build from glucose monomers bound with strong glycosidic bonds, effect on lower level of decomposition potential [Hills et al., 2020]. The estimated annual production of cellulose is 200 billion tons [Ragauskas et al., 2006, Sánchez and Cardona, 2008, Zhang, 2008]. Due to the wide use of lignocellulosic biomass, the literature discusses the use of various alternative sources of potential acquisition of this raw material. Acetate based on wood cellulose was used in the conducted research. There is a clear trend of searching for sources in waste from the local agricultural and forestry industry, which results not only from attempts to better manage the masses of waste generated in these industries, but also from the need to avoid the use of plants that can be used for food and feed purposes for other applications, e.g. energy. Published research shows promising results on the potential of acetate production using cellulose from coconut shells [Amaral et al., 2019], rice husks [Das et al., 2014] or rice straw [Fan et al., 2013].

In the acetate compostability test conducted under controlled conditions, the acetate waste material exhibited a decomposition rate D = 75,3% (expanded uncertainty determined for the coverage factor k = 2 at the confidence level p = 95%) after 84 days (12 weeks test duration according to PN-EN 14045:2005). The result reflects the difference between the initial dry mass of waste used in the process and the dry mass of waste sifted out at the end of the experiment.

In a study by reference [Vicman et al. 2015], researchers investigated the degradation of cellulose powder in a lab-scale composter bin. They found that during the composting process, the maximum temperature exceeded 60 °C for at least one week. This indicates that cellulose powder biodegrades at a rate of approximately 69% after 65 days. Additionally, the degradation of cellulose-based products appears to be influenced by environmental factors such as temperature, moisture, and oxygen availability. Interestingly, the addition of certain substances (such as salts or pigments) can hinder cellulose decomposition, as noted in reference [Gómez and Michel, 2013].

As per Vaverkova research [Vaverkova and Adamcova. 2015], conducted under regime of the same procedure as presented in this paper [PN-EN 14045:2005], composting of the feedstock built from compost containing synthetic material and treated in aerobic conditions and temperature 58 °C (±2.0ºC), within 154 days, resulted in biodegradability rate above 80%.

A per Parida [Parida et al. 2022] the biodegradation of used cellulose acetate filters were reached the 92,1%, and no cellulose acetate peak

Table 1. Phytotoxicity test results

Sample	Oats seeds		Cress seeds			Green cucumber seeds	
	The number of germinated seeds	Root length [mm]	The number of germinated seeds	Root length [mm]	Shoot length [mm]	The number of germinated seeds	Root length [mm]
Soil substrate	3	27.0	9	51.2	45.4	0	–
Compost	3.7	14.1	9	25.7	25.7	0	–
1% acetate compost + 99% compost from green waste	2	16.7	9	25.2	25.2	0	–

(within Gel Permeation Chromatography procedure) was observed in created compost samples after 151 days of performed experiment due to ISO 14855-1 standard.

Composting processes can break down compostable polymers, and mineralization may occur during the composting period for other biodegradable materials. Industrial composting helps reduce the volume of bioplastic waste in an environmentally friendly manner. Identifying conditions for safe compost production is crucial [Ahzan et al. 2023].

The obtained compost was used for acute phytotoxicity assessment using the PHYTOTEST-KIT method. To perform the determination, a soil substrate without additives was used as a control sample, and as real samples: 100% compost from green waste and compost with a composition of 1% acetate + 99% compost from green waste. Seeds of three plants were used to make the determinations: oats, cress and green cucumber. Green cucumber seeds did not germinate in both the control sample and the test sample. For both oats and cress, germination and root growth were observed for the control sample and the tested samples. In the case of oats, no shoot growth was observed, in the case of cress, the shoot length was observed and analysed. Three replicates were made for each substrate, each with 10 seeds. The table below presents the obtained results expressed in the average for each repetition (Table 1). The analysis performed shows that in the method used, only 81 out of 210 seeds germinated on the substrates used (39%). Of which 0 green cucumber seeds, 29% oat seeds (for compost with the addition of acetate: 20%) and as much as 90% cress seeds for each substrate and control sample. At the same time, cress is the only plant for which shoot growth has been observed. Compared to other substrates, cress seeds growing in the substrate with the addition of acetate are characterized by shorter root length, on average 19 mm, and for compost from 100% green plants -35.7 mm. The length of cress shoots for both types of compost is similar: 25.2 mm (compost with additives) and 25.7 mm (compost without additives). Significantly better growth of both roots and shoots was achieved when cress seeds were sown on the control soil.

Phytotoxicity, the adverse effect of chemical compounds on plant life, is a critical parameter in assessing the quality of compost and its suitability for agricultural application. Statistical evidence from industrial composting facilities indicates that biodegradable polymers, including cellulose acetate, exhibit varying degrees of degradation and phytotoxicity. A per Bandini [Bandini et al. 2020] water-soluble lactic acid from composted cellulose acetate has significant impact on pH level reduction, what affects seed germination and germination indexes.

CONCLUSIONS

Research indicates that effective decomposition depends on specific conditions and sufficient processing time. Acetate, a plastic type derived from cellulose, can be composted, but its breakdown rate varies. The obtained results from the performed test exhibit comparability with the current state of the art in this field. Factors like temperature, moisture, and oxygen availability influence cellulose-based product degradation. Industrial composting plays a crucial role in reducing bioplastic waste while ensuring safe conditions. Additionally, studies have explored alternative sources of cellulose for acetate production, such as coconut shells, rice husks, and rice straw. In addition to the points mentioned earlier, it's worth noting that composting processes can effectively break down compostable polymers, including cellulose-based materials. During composting, mineralization may occur, contributing to the overall decomposition.

Industrial composting facilities play a crucial role in reducing the volume of bioplastic waste in an environmentally friendly manner.

Identifying optimal conditions for safe compost production remains essential. Researchers continue to explore various sources of cellulose for acetate production, such as coconut shells, rice husks, and rice straw. By understanding the intricacies of composting and its impact on biodegradable plastics, we can make informed decisions to promote sustainable waste management practices.

The obtained compost was evaluated for phytotoxicity using the PHYTOTESTKIT method. Real samples included 100% compost from green waste and a mixture of 1% acetate with 99% compost from green waste. Green cucumber seeds did not germinate in either the control sample or the test sample. For oats and cress, germination and root growth were observed in both the control and test samples. However, oats did not exhibit shoot growth, while cress showed shoot length. Across substrates, only 81 out of 210 seeds germinated (39%). Specifically, green cucumber seeds showed no germination, oat seeds had a 29% germination rate (20% for compost with acetate), and cress seeds had a high 90% germination rate for each substrate. Cress, the only plant with shoot growth, had shorter root length (average 19 mm) in the acetate-added substrate compared to 100% green plant compost (35.7 mm). Shoot length for cress was similar in both types of compost: 25.2 mm (with additives) and 25.7 mm (without additives). Notably, cress seeds performed best when sown in the control soil. Overall, assessing phytotoxicity is crucial for compost quality, and biodegradable polymers like cellulose acetate can impact seed germination and growth.

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