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COMMON REED AS A NOVEL BIOSOURCE FOR COMPOSITE PRODUCTION

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Abstract
The production of plastics has grown significantly in the last decades, and the trend is expected to continue, depending mainly on increasing demand from various industries, such as packaging, construction, and consumer goods. Today, researchers are looking for new biobased sources to replace fossil fuel-based plastics. Common reed bed along the coast in Baltic Sea present a sustainable resource that could play a role in the future circular economy, but the potential of reeds as an unused biological material, effectively binding nutrients and carbon, has been only partially identified. This study examines the potential of common reed as a sustainable, novel composite material. Common reeds were harvested both in summer and winter, and various blends were analyzed to determine their suitability for composite applications. The mechanical characterization shows that the integration of common reed fibers into polyethylene matrices has been shown to enhance crucial properties such as tensile strength and yield strength, demonstrating that common reed can be utilized in composite materials, thereby reducing reliance on fossil-based plastics.

1. Introduction
The path towards a circular economy for plastics and composite materials, while enhancing circularity, strongly focuses on phasing out fossil fuel-based plastics. A promising solution to the environmental issues is the shift towards biobased and/or biodegradable materials. Biobased plastics are made fully or partially from biobased resources, with the integration of biobased carbon being a crucial element.
Currently, bioplastics constitute only 1-2% of all plastics, yet there is potential to replace up to 90% of fossil-based plastics with them. Plastic and composites are used for several different sectors and articles, due to their high flexibility and endless possibilities due to the possibility to vary their mechanical properties over a wide range, at a reasonable cost [1]. An essential area for substituting fossil-based plastics with biobased alternatives is in short-term use products for consumers, such as packaging, which represents the most significant usage area for conventional plastics [2].

Cellulose-based reinforced composites have been of interest for researchers and engineers over the past years [3]. By adding biobased fibers to composite material it is possible to modify the mechanical properties and biodegradability or decreasing the carbon footprint of composite [4]. Various engineering sectors, including automotive interiors, have been replaced by plant-based fibers, including sisal, hemp, kenaf, flax, ramie, jute and rice husk as examples, have showed good mechanical characteristics for fiber reinforced composites [5], [6], [7], [8]. The characteristics with low density, light weight, low cost, decent thermal, electrical and acoustic insulation properties combined with minimal health hazard and energy consumption makes these natural fiber-based composites attractive choices instead of conventional synthetic fibers [9].

Researchers around the world are actively searching for new novel natural fibers for solving the challenge of composites. One fiber that researchers have suggested as an interesting alternative to reinforce novel composites is *Arundo donax* L. [10], [11]. This interest in giant reed is not only due to the interesting mechanical features shown by these fibers [12], but also because of its fast growth, the possibility of cultivating it in marginal soils and with wastewaters. For instance, Suárez et al. studied the mechanical properties of giant reed fibers in thermoplastic composite materials [13]. They found that these composites show improvement in flexural and tensile elastic modulus and the use of *Arundo donax* L. shows great potential to be used as reinforcement in polymer composites. On the other hand, giant reed composites also provide some other interesting features, such as the increase in the biodisintegration rates when introduced into a PLA matrix [14]. The use of this plant within a biorefinery context for the obtaining of valuable compounds and materials [15] also provides added value to the use of natural sourced materials, as part of a strategy for the control of invasive plant, and finding a closed loop strategy for the use of waste, also useful for the remediation of polluted soils and the reduction of soil losses [16].

Another novel natural-based material, with closed-loop strategy for harvesting waste, is common reed. Common Reed (*Phragmites australis*) is a perennial grass growing in shallow waters, shores, and wetlands, forming dense stands 1–3 meters tall and spanning up to hundreds of hectares. Common reed bed along the coast in the Baltic Sea present a sustainable resource that could play a role in the future circular economy. Common reed beds have the capacity to sequester nutrients and carbon, which are the major contributors to the Baltic Sea Eutrophication and the climate crisis. A potential strategy to recycle nutrients and close the nutrient cycles in the Baltic Sea ecosystem is coastal management, aiming to remove nutrients by harvesting biomass. Significant amounts of nutrients accumulate in various parts of emergent or submergent macrophytes during the growing season, such as reeds [17].

Harvested biomass can be reused for nutrient recycling, thereby closing the loops by returning extracted nutrients to the ecosystem. Reed contains significant amounts of nutrients contributing to Baltic Sea eutrophication, with up to 10 kg of phosphorus and 100 kg of nitrogen per hectare. Harvesting reeds can remove nutrients from coastal ecosystems while providing a climate-friendly raw material for various purposes. By harvesting reed beds, nutrients can be removed from ecosystems with biomass. Despite the rapid proliferation of common reeds and their biological characteristics, there are still limited applications for them. While some research has been done on reed value chains, there are still gaps that require further research. The potential of reeds as an unused biological material, effectively binding nutrients and carbon, has been only partially identified.

In previous studies, value chains for reed have been identified, including products like biogas, composting, and cultivation materials. However, higher-value products have not yet found their place in functional value chains. Manufacturing products according to circular economy principles requires reducing waste, replacing fossil materials like plastics, and developing responsible and sustainable production processes. There's an increasing focus on renewable solutions, driven by the negative impacts of plastics and a growing awareness of global waste issues, pushing material producers and industries towards environmentally friendly solutions throughout a product's lifecycle.

Albretch et al. (2023) studied the mechanical characteristics of common reed stems in comparison to wood. They concluded that common reed is suitable raw material for bio-based load bearing structural materials [18]. Kraiem and collaborators produced composites based on HDPE at low loadings (maximum of 10 % by weight) and reprocessed them to simulate a recycling process; these authors found that reprocessing resulted in a better dispersion of the filler within the matrix, as easily understood, therefore obtaining improved properties after three reprocessing cycles [19]. More interestingly, the incorporation of such low amounts of reed provided an improved behavior after reprocessing, due to a stabilization effect provided by the biomass. This has been recently pointed out in other research works, where the analysis of potential stabilizing and antioxidant behavior of lignocellulose is being analyzed. In a different approach, Albretch et al. proposed the use of common reed stems for the production of load-bearing applications, bringing them together with wood glue (polyurethane resin). According to these authors, reed stems are a promising source for obtaining building materials.

This study examines the potential of common reed as a sustainable, novel composite material. It shows the characterization of the common reed harvested at two moments (winter and summer) and provides a first approach to its use for high-loaded composites.

2. Materials and methods

2.1. Plant characterization

Common reeds were harvested and collected both in summer and winter, with stems of an average of 1 cm, in South Finland during 2023. The plants that were harvested at the end of the summer period were separated in three parts: stems, leaves and flowers for characterization tests. From the plants harvested during the beginning of winter period only stems were characterized.

The content in ashes, lignin, cellulose and hemicellulose were determined using standardized methods, briefly described. Lignin content was determined using the Klason method [20] by hydrolysis with H2SO4. Holocellulose content was obtained through a gravimetric method, by samples delignification with acetic acid and sodium chlorite, as described by Browning [21]. Total cellulose content was derived from the holocellulose sample by digestion of hemicellulose with NaOH [22]. Hemicellulose content was calculated by subtracting cellulose from holocellulose. Three replicates from different batches were used, and results are presented as average values with standard deviations.

The thermogravimetric tests were carried out in order to determine the thermal stability of the materials. These studies were performed in a TGA 4000 from Perkin Elmer, using a sample of nominally 10 mg, from 30 to 600ºC at a heating rate of 10 ºC/min in a nitrogen atmosphere. The surface composition analyses were performed by Fourier transform infrared spectroscopy (FTIR). FTIR spectra were obtained in a Perkin Elmer spectrum Two device (Perkin Elmer, Waltham, MA, USA) equipped with an attenuated total reflectance (ATR) device, from 4000 to 500 cm^{-1}, at a resolution of 16 cm^{-1}, obtaining each spectrum as the average of 16 scans.

2.2. Composites Obtaining and Characterization

Composites obtaining were carried out following: Mixed common reed with stems, flowers and leaves (A) entire stems for summer (B) or winter (C) were milled and sieved for fractions of 0.075-0.8 mm to produce natural fiber composites (NFC) by dry blending with polymeric matrics and subsequent compression molding/extruder-injection molding. Polyethylene (Revolve N-461) was used as a matrics polymer to produce the composites, and various blends were analyzed to determine their suitability for composite applications. These blends were processed using twin-screw extrusion and molded, with their thermal properties, thermogravimetric analysis, and mechanical characteristics being assessed.

2.3 Mechanical characterization

Quasistatic tension tests are used to characterize the mechanical properties of the four different sample categories that include the pure PE (0 % Reed), and the PE reinforced with 20% fiber loading of reed A, B and C. ISO 527-2: test guidelines and condition to conduct the experiments on specimen type 1B was followed for these tests. A test speed of 10 mm/ min was used for all studied sample categories. Five specimens from each sample category were tested, and the mean stress-strain data is used for the characterization. The analyses of required mechanical properties are based on the nominal stress-strain data.

3. Results

3.1. Plant characterization

Table 1 summarizes the results from the composition analyses performed to the different samples of reed. It can be observed that mixed reed shows the higher humidity and ashes contents, possibly due to the incorporation of leaves within this group. Leaves are known to store salts and minerals [23]. Lignin content in the plant is similar despite the season of harvesting, only resulting in lowered amounts for the mixed reed, due to the presence of leaves in this fraction; lowered lignin content in leaves has also been found for other species of reed [11]. Finally, holocellulose content is about 76% for the three different species, although with different carbohydrates depending on the fraction. Winter reed exhibits the higher cellulose fraction, while summer and mixed reeds provide a lower content of that compound, with an increased fraction of hemicellulose. Other authors have reported similar composition, i.e. about 40 % cellulose, 26 % hemicellulose and 12% for lignin [24]. Contents around 30% of lignin have been reported previously in literature for giant reed [23], [25], [26], [27], while this plant exhibits usually a lower cellulose content, thus making common reed (Phragmites australis) a promising source for cellulose compounds.

Table 1. Compositional results for the different samples of common reed (in %)

	Humidity	Ashes	Lignin	Hemicellulose	Cellulose
Winter reed	5.66±0.23	7.60±0.20	25.87±1.25	20.92±0.83	55.09±0.36
Summer reed	5.37±0.01	8.82±0.21	24.01±0.47	28.07±0.55	48.75±1.03
Mixed reed	7.41±0.13	12.83±0.32	21.29±0.51	25.38±0.14	48.87±0.32

3.2. FTIR spectroscopy

Figure 1 shows the recorded spectra for the different samples assessed. Typical bands for lignocellulosic materials can be observed, namely at 3000-3700 cm^{-1}, assigned to O-H stretching in biomass; a double peak at 2917-2850 cm^{-1}, attributed mainly to C-H aliphatic groups in hemicellulose [26]; 1733 cm^{-1}, attributed to C=O stretching in lignin and hemicellulose[28], [29]; broad intense peak centered at 1034 cm^{-1} is observed for all the samples; this is attributed to C=O stretching ring vibration in cellulose [30]. Summer reed shows more prominent bands on the areas related to hemicellulose, particularly in the double peak close to 2900 cm^{-1}, as also observed for the composition analysis. The higher hemicellulose content is related to a lower thermal stability, as also observed in thermogravimetric analysis.

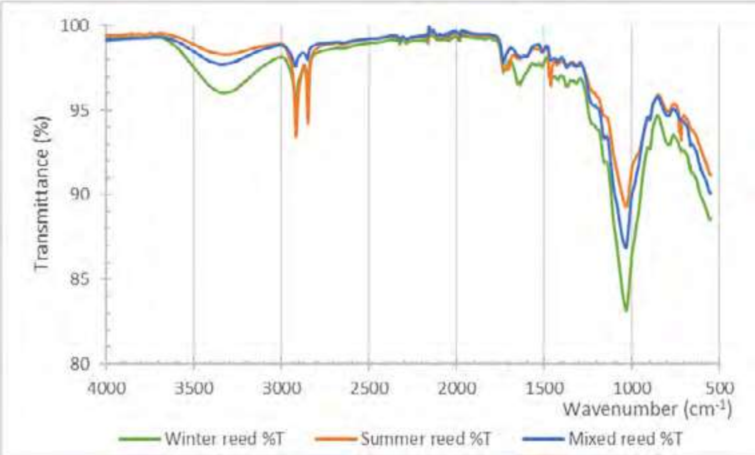

Figure 1. FTIR spectra for untreated reed samples

3.3. Thermogravimetric analysis (TGA)

From the thermogravimetric analysis the thermal stability of the different samples can be obtained. As observed from figure x, the winter reed shows more thermal stability than summer or mixed reeds, as explained above, due to the lower hemicellulose content. The mixed reed, on the contrary, shows a significantly lower onset temperature, due to the incorporation in this fraction of leaves, also exhibiting the higher amount of ashes (as usually minerals are stored there). This material exhibits three degradation steps, at the temperatures found in table 2. Remaining samples show the degradation occurring at two main moments, between 240-250 ºC, related to hemicellulose depolymerization [28] and at 270-290ºC (higher for winter reed samples).

Table 2. Results from TG analysis

	Onset (ºC)			Derivative peaks (ºC)			Ashes (%)
Winter harvested reed, stems		253.7	286.1		279.5	344.3	20.6
Summer harvested reed, stems		243.9	270.5		268.6	338.8	22.8
Mixed summer harvested reed	208.4	244.1	287.3	222.7	279.2	287.2	26.2

3.4. Mechanical characterization

The experimental stress-strain result shows that reed fiber-reinforcement decreased the ductility of the pure PE, however enhanced the key mechanical properties related to strength, as shown in figure. 2.

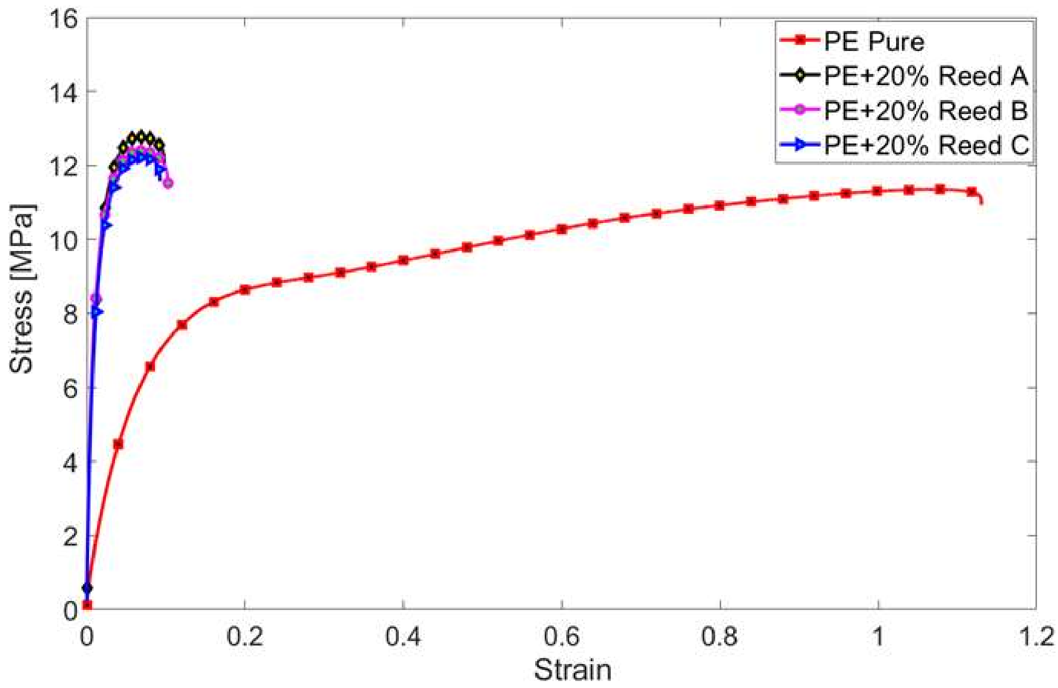

Figure 2. Experimental stress-strain relationship of the four sample variants

4. Conclusions

This study demonstrates that common reed can be utilized in composite materials, thereby reducing reliance on fossil fuel-based plastics. Additionally, it offers the potential for common reed to serve as a carbon sink in durable products. The analysis shows that common reed has a robust composition of lignocellulosic materials, and is suitable for various composite application, exhibiting comparable lignin and cellulose contents across different seasons. The higher cellulose fraction in winter-harvested reeds show seasonal variability also in material properties, which can be optimized for specific application. However, the determination of cellulse/lignin content should be determined further to be able to understand the variation of seasons or harvesting sites.

From the thermogravimetric analysis, the results shows that the thermal stability of reed-based composites can vary significantly depending on the blend and harvesting season. In thias study common reed were not treated chemically, which may lead to better thermal stability and should be studied further. The mechanical characterization shows that the integration of common reed fibers into polyethylene matrices has shown to enhance crusial properties such as tensile strenhgt and yield strength. While there are benefits achieved, a reduction of ductility is making composites stronger but less flexible.

The utilization of common reed, especially from dominant growth along the Baltic coast, could contribute positively to environmental management efforts by mitigating eutrophication through nutrient sequestration. This aligns well with circular economy principles and resource efficiency.

In conclusion, while promising, the application of common reed in biocomposites is still in the early stages. Future research should focus on optimizing harvesting times, blend proportions, and processing techniques to maximize the material´s functional properties and environmental benefits. This could create the way for a sustainable alternative to traditional fossil fuel-based plastics, contributing to a more resilient and environmentally conscious materials science landscape.

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