Valorisation of industrial food waste to produce pulp for the textile industry

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In the research for new environmentally friendly, biobased, and biodegradable raw materials to meet the needs of the textile industry, the possibility of processing peach wastes from the food industry (compote and juice production) to develop regenerated cellulosic fibres is investigated. The aim is to upcycle a readily available agro-waste like peach residues, find new alternative sources to produce manmade cellulosic fibres and fabrics, and possibly free up space of arable land which is currently occupied by industrial crops aimed at the textile industry, such as cotton. The investigated methodology involves the extraction of the cellulose from the peach peal and tissue to produce pulp and the regeneration of fibres by dissolving and spinning the cellulosic pulp. The present study focuses on measuring the most critical parameters that determine the effective use of the produced pulp in the textile industry.

Textile fibres are divided into two categories, natural and man-made. Natural fibres have been exploited by mankind for thousands of years and can be of plant or animal origin (Sayyed et al., 2019). However, the rapid growth of the textile industry in the 20th century could not be met with natural fibres only, as their production is seasonal, and supplies are limited. On the other hand, man-made fibres can be derived either from petroleum products (synthetic fibres), or from the regeneration of cellulose.

Regenerated cellulose fibres are produced from dissolving pulp, which is the result of chemical refinement/purification treatment, of wood and cotton mainly. In particular, the global production of pulp from softwood, such as fir and pine, and hardwood, such as beech and eucalyptus, amounts to 85%, while 10% comes from cotton linters which are discarded during the ginning process (Sixta, 2006). The dissolving pulp from these sources has a high cellulose content (> 90%), uniform molecular-weight distribution and a high level of brightness. Nevertheless, in recent years, a wealth of research has been recorded to study the production of pulp from plant raw materials other than wood (Plakantonaki et al., 2022), such as bamboo pulp which is commercially available (Ribas Batalha et al., 2012). The use of lignocellulosic agricultural by-products can potentially increase the pulp production and the market share of bio-based textile products, without increasing the agricultural land covered by industrial crops nor contributing to deforestation.

According to the data of the Hellenic Statistical Authority (ELSTAT, 2019), the annual production of peaches/nectarines throughout Greece was 630.2 thousand tons. This number ranks the country in 6th place in the world production of peaches based on the Food and Agriculture Organization (FAO).

Data offered by the Union of Canners of Greece, 60% of the total peach production goes to the food processing industry. During the production processing of peeling and kerning, up to 30% by weight of the product is discarded. The peach core is high in lignin and low in cellulose and makes up about 7% of the weight of the fruit. For the above reason, its use is not chosen for cellulose extraction, while it finds application as biofuel, often in the industrial units themselves.

The Lyocell method is an alternative to the viscose method to produce regenerated cellulosic fibres (Sayyed et al., 2019; Opperskalski et al., 2022). During this method, cellulose is dissolved directly in an aqueous solution of N-methylmorpholine N-oxide (NMMO) without the use of toxic solvents. Furthermore, NMMO is considered a green solvent (Jiang et al., 2020) and is 99% recyclable in the Lyocell process. The production process includes the following steps: 1) dissolution, 2) filtration, 3) spinning, 4) washing and 5) drying. Given the quality of the final fabric, as well as its environmental advantages, the Lyocell method is used commercially with increasing trend and is now the third most frequently used man-made cellulosic fibre after viscose and acetate cellulose, taking a market share of around 4% in the category of man-made cellulosic fibres (Opperskalski et al., 2022).

The production processes and product characteristics of the various regenerated cellulosic fibers have different raw material (pulp) specification requirements. Critical parameters, which are specific for the lyocell method include (Jiang et al., 2020):

(a) Degree of polymerization (DP) and solubility. The DP of the dissolved pulp directly affects the mechanical strength of the Lyocell fiber. In theory, the higher the DP, the better the mechanical strength of the fibre. However, an excessively high DP can lead to poor solubility and increased viscosity of the spinning dope. Balancing the

relationship between DP and pulp solubility has a great impact on the spinning process and the performance of the corresponding fibre. According to Jiang et al (2020) the optimal DP values are between 650 and 750.
(b) α-cellulose. Zang et al. (2007) demonstrated that a spinning dope with high hemicellulose content can present good mechanical properties since it can be processed at higher concentrations. During the production of the spinning solution, the hemicelluloses in the pulp can also be dissolved in the aqueous NMMO solution, however an excessively high amount of hemicellulose can reduce the mechanical strength of Lyocell fibres (Jiang et al., 2020). Typically, dissolving pulps for Lyocell method have a percentage of α-cellulose greater than or equal to 92% (Zhang and Tong, 2007).

The process of extracting cellulose and producing dissolving pulp from peach fruit waste from the food industry is subject to patent application. The experimental results presented in this study establishes proof of concept after initial experimentations following a Plackett-Burman design.

α-cellulose content was tested according to the method of Ritter (1929). Viscometry measurements were performed to determine the degree of polymerization (DP) and molecular weight in peach-extracted cellulose. Viscometry measurements were performed following the international standard ISO 5351:2010. Two viscosity measurements were made in each solution and the results are presented in Table 1 as an average of the measurements. The determination of the number of monomer units in the cellulose molecule is done by first calculating the molecular weight (MW) by using the following correlation equation (Kim et al., 2001):

$$[\eta] = 0{,}98 \times 10^{-2} \times MW^{0,9}$$

Next, DP is measured by dividing MW of the polymer with the MW of the cellulose monomer.

Table 1. Measurements on the final cellulose product.

Sample No	[η](ml/g)	MW (g/mol)	DP
1	211	65239	402
2	200	61613	380
3	311	100393	619
4	291	93246	575
5	225	70066	432
6	325	105427	650

In all samples, the value of α-cellulose was 93%. In the case of DP sample 6 is within the optimal limits for application in the Lyocell technology, while sample 3 is very close. Thus, the cellulosic pulp produced under optimal conditions of this experimental parameters screening appear as able to be used as a sole source to produce lyocell fibre. However, its mixing with commercially available dissolving pulps can further support and guarantee the mechanical properties of the final cellulosic fibre.

By choosing the optimal purification method of peach waste, the extracted cellulose macromolecules have a molecular weight suitable to be used as a raw material to produce fibres for the textile industry, while the percentage of α-cellulose in the final product is within the desired range. The suitability of the resulting dissolving pulp is confirmed by subsequent experimental steps that result in the production of regenerated fibre and yarn from peach waste. The optimization of the production parameters continues as well as the study to improve the important properties of the yarn such as strength and flexibility.

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