By-products from the coffee industry as additives in the preparation of poly(lactic acid), PLA based composite films for food packaging applications

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Keywords: PLA, coffee silverskin, film, circular economy
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Abstract
In the food packaging industry, significant efforts have been dedicated to addressing the pressing market demand for environmentally friendly and sustainable products. One area of focus involves the development of new materials as alternatives to petrochemical-based polymers, with compostable and biobased polymers garnering considerable attention. Additionally, there is growing interest in utilizing waste materials from agriculture and the food industry. This study aimed to create multifunctional eco-sustainable systems by combining poly(lactic acid) (PLA) as a biopolymer matrix and coffee silverskin, which is a by-product of the coffee roasting process. The results showed that good silverskin dispersion and distribution into PLA was achieved and that bleaching led to better interfacial interaction. The addition of silverskin, in any proportion to the polymer matrix did not affect the thermal and physicochemical properties of the polymer. However, the antioxidant activity was increased gradually with increasing addition of coffee silverskin and good oxygen and water vapor barrier properties were found for all nanocomposites.

Introduction

A large amount of food waste is generated in the EU, estimated at around 100 million tonnes per year, of which almost 30% comes from the agri-food supply chain (Gustavson et al., 2011). Such production of wastes and by-products causes high environmental impact in terms of land use and high carbon footprint as well as high blue water footprint (Vermeulen et al., 2012). Considering that coffee is the second largest trade market with an annual global production of 105 million tons, the coffee industry generates substantial quantities of waste throughout the processing stages from fruit to cup (Toschi et al., 2014). The yearly accumulation of coffee waste is estimated to exceed 23 million tons. By-products primarily originate from the separation of shells and mucilaginous components from the fruits and their composition varies depending on the specific processing techniques employed, such as wet or dry processing, as well as subsequent stages like roasting and brewing. Solid residues include coffee pulp, coffee husks, silverskin and spent coffee (Murthy et al., 2012).

The new trend in polymer-based packaging is to use biodegradable or compostable polymers instead of commonly used oil-based materials. In this direction, poly(lactic acid) is a polymer commonly used in many applications including food packaging. In order to enhance the properties of the basic polymer several additives have been used. The purpose of this work is to study the effect of adding coffee silverskin (ss) in PLA matrix and prepare films for food packaging. In order to achieve this objective, several ss loadings were investigated and surface treatment was conducted for adequate dispersion. Films were then analyzed in relation to the morphological and thermal characteristics of these biocomposites.

Material and methods

Coffee silverskin (ss), derived from the roasting of a mixtures of Arabica and Robusta coffee varieties, were provided by AVEK S.A. (Thessaloniki, Greece). PLA composite films were prepared by the solution casting method. PLA films in different concentrations of coffee silverskin (2.5 wt.%–20 wt.%) were prepared from 7.5 wt.%/vol chloroform solutions (Figure 1).

Figure 1. PLA based composite films with 2.5, 5, 10, 15 and 20 wt% of silverskin.

Physicochemical properties of the films were measured via FTIR spectroscopy, SEM microscopy, DSC calorimetry. Moreover, Oxygen and CO_2 permeability was measured together with water vapor permeability. Finally, the antioxidant activity was evaluated, using the DPPH (2,2-diphenyl-1-picrylhydrazyl) test. The reaction

kinetics were followed by the disappearance of the DPPH• reactant as given by the absorbance measurement from 400 to 700 nm (max. absorbance: 516 nm) using UV spectrophotometer (Shimadzu Spectrophotometer UV-1800). The percent antioxidant activity (AA) of the films was calculated by measuring the absorbance (ABS) at 516 nm taking the absorbance of the DPPH solution as control

Results and discussion

Results from FTIR spectroscopy revealed the incorporation of silversking in the polymer matrix. The morphology of the films was characterized by SEM microscopy, and adequate dispersion was revealed. The thermal properties of the composite films were similar to the neat polymer PLA, as revealed by DSC scans. The thickness of films increased along with an increased amount of coffee silverskin added into the film solutions. The incorporation of coffee silverskin into PLA film improved neither the solubility nor the degree of swelling of the film in water. The water vapor transmission rate decreased with the incorporation of silverskin, with the largest percentage of filler being equal to the control film.

Finally, an increased antioxidant activity with increased amount of ss added was observed (Figure 2). Larger values were measured at higher times. The primary source of antioxidant capacity in SS can be attributed to the presence of polyphenols. These polyphenols encompass a diverse range of compounds that possess properties for scavenging free radicals. Coffee silverskin, also contains various bioactive constituents, including melanoidins, caffeine, and dietary fibers, all of which can contribute to the antioxidant activity. Notably, melanoidins are complex compounds with high molecular weight that are formed during the roasting process of green coffee beans through the Maillard reaction between amino acids or proteins and sugars (Iriondo et al., 2016).

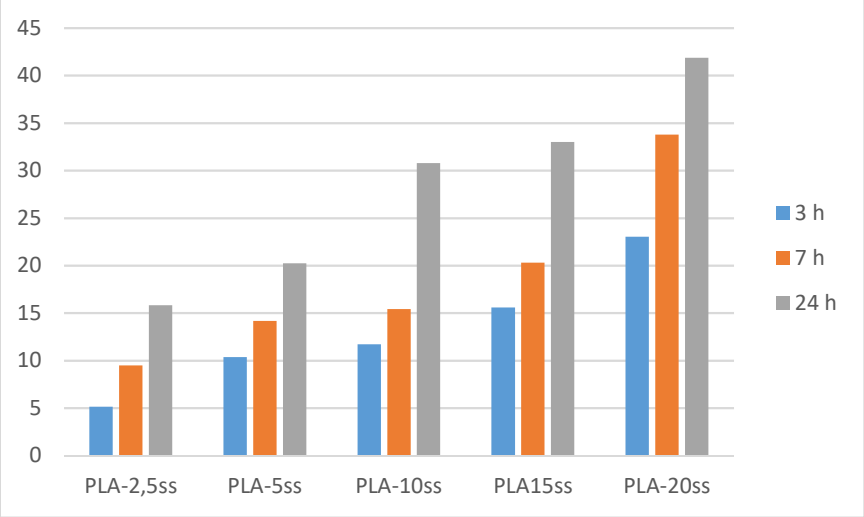

Figure 2.Antioxidant activity of PLA based composites with different amounts of silverskin after different oxidation times.

Conclusions

Concluding, the integration of coffee silverskin, coffee-industry by-product into polymer technology should be regarded as a novel approach for their economic and ecological utilization. Efficient management of these by-product has the potential to significantly reduce the manufacturing costs of polymers and polymer composites, while simultaneously adding value to them. This enhancement of economic aspects in coffee production is accompanied by the advantageous chemical composition of coffee silverskin by-product, particularly its high content of antioxidant compounds, which sets them apart from many other lignocellulosic materials. Further studies associated with these materials should be focused on evaluating changes in processing, structure, mechanical, and thermal properties of composites subjected to accelerated aging tests

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