Journal of Cleaner Production 167 (2017) 68–74

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Post-harvest tomato plants and urban food wastes for manufacturing plastic films

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ARTICLE INFO

Article history:
Received 13 April 2017
Received in revised form
5 August 2017
Accepted 18 August 2017
Available online 18 August 2017

Keywords:
Biomaterials
Biopolymers
Blend films
Extrusion
Municipal food wastes
Post-harvest tomato plants

ABSTRACT

Poly(vinyl alcohol-*co*-ethylene) was compounded with 2–10% post-harvest tomato (PHT) plant powder and processed by single-screw extrusion to yield composite films. Upon increasing the filler content, the values of the mechanical properties indicators were found to decrease as follows: Young's modulus from 1797 to 750 MPa, stress at yield from 36 to 15 MPa, maximal stress from 39 to 15 MPa, stress at break from 35 to 14 MPa, and strain at break from 6.6 to 4.3%. The results are discussed in comparison with other composite films containing poly(vinyl alcohol-*co*-ethylene) and water soluble biopolymers obtained by alkaline hydrolysis of fermented municipal biowastes, and with other commercial materials, such as starch based and low density polyethylene mulch films. Depending on the intended application, the post-harvest tomato blend films may be competitive for cost, performance and sustainability.

1. Introduction

The valorization of biowastes from municipal and agriculture sources as feedstock for the production of added-value biobased products is a topic currently addressed by the European Commission calls for research proposals (EU commission, 2017). In this context, several papers have reported the manufacture, properties and performance of soluble biopolymers (BPs) obtained from the above biowastes (Franzoso et al., 2015a,b, 2016). The BPs are high molecular weight biopolymers, which are isolated from the acid or alkaline hydrolysates of the sourcing biowastes. In essence, they are soluble fragments of the pristine biowaste lignocellulosic proximates. They are constituted by C moieties, which save the chemical memory of the native polysaccharide, protein, fat and lignin proximates present in the parent biowaste.

The BPs have been demonstrated multipurpose products (Montoneri, 2017; Arshadi et al., 2016) for use in the chemical industry, agriculture and animal husbandry. Particularly interesting are the papers reporting the performance of the BPs as biostimulants for the cultivation of tomato (Sortino et al., 2014) and maize (Rovero et al., 2015) plants, and as fillers for manufacturing solvent cast films (Franzoso et al., 2015a,b, 2016). Moreover, the post-harvest tomato and maize plants have been shown suitable feedstock for hot pressing manufacture of binderless fiberboards to be used for many different purposes in both the building construction and the home furnishing (Evon et al., 2017). These findings are well in line with the EU zero waste strategy (Zero Waste Europe, 2013). They prospect a desirable integration of both municipal and agriculture biowastes by recycling C repeatedly over the agriculture and urban environment. The success of this scenario depends on feedstock availability and processing costs, and on products performance. As widening the number of case studies offers more perspectives of success, the present work reports the manufacture and properties of composite plastic films obtained from a synthetic polymer from fossil feedstock and grinded post-harvest tomato (PHT) plants.

Tomato plants are grown worldwide for their edible fruits, with

Abbreviations: PHT, Post-harvest tomato; BPs, Soluble biopolymers; EVOH, Polyethylene-*co*-vinyl alcohol.

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http://dx.doi.org/10.1016/j.jclepro.2017.08.160
0959-6526/

thousands of cultivars. In 2014, world production of tomatoes was 171 Mt, 31% in China, followed by India, the United States and Turkey as the major producers (FAOSTAT, 2017). Tomatoes accounted for 23% of the total fresh vegetable output of the European Union, more than half coming from Spain, Italy and Poland (De Cicco, 2016).

On the other hand, biobased plastics are key target materials of EU calls for research proposals (EU commission, 2017). Bioplastic packaging consumption has been estimated to be 125 kt in 2010 with an estimated market value of 454 M$ (Roland-Holst et al., 2013). Yet, bioplastics represent currently only a small portion (under 1%) of the global market share of plastics (European bioplastics, 2016; Storz and Vorlop, 2013; Plastermat, 2013), which should be around 1–2 Mt/yr. Thus, bioplastics are a growing opportunity to recycle biowastes and market them in the form of plastic objects.

The above figures for both tomato plant production and bioplastics' market perspectives pose worthwhile scope for research effort aiming to valorize PHT plants for the production of new biobased plastic objects. One more reason for focusing research on biowastes for the production of biobased plastics is the fact that most biopolymers for manufacturing plastics are obtained from dedicated crops. However, the use of land to cultivate plants dedicated exclusively to the production of energy, materials or chemicals raises much socio-environmental and moral concern. Negative impacts on land, water, biodiversity, and food production and price arising from this practice are matter of dispute (Green facts, 2017; FAO, 2008). On the contrary, the alternative use of biowastes as feedstock for the above scopes is unanimously welcome.

Some studies have already been performed on PHT plants as source of BPs (Franzoso et al., 2015b) for manufacturing through solvent casting composite mulch films to be used in agriculture. Generally, a plastic film must satisfy a number of requirements. It must be mechanically strong to withstand high shear stress and still recover its original shape. Moreover, it must be flexible, elastic, easily processable and not expensive. No single polymer can satisfy all requirements for the many diversified uses of plastic films. Thus, composite films are made. The composite films made with BPs sourced from PHT contain a polyethylene commercial copolymer from fossil source, such as polyethylene-*co*-vinyl alcohol (EVOH) or polyethylene-*co*-acrylic acid (Franzoso et al., 2016, 2015a, respectively), and 2–40% BPs as fillers.

There are several reasons that do not allow fabricating plastic films made entirely from neat BPs. One is that BPs do not have melting and film forming properties. They are only soluble in water at pH values greater than 4. The evaporation of their water solutions results in the deposition of the solute in powder or fragile sheet form. Thus, neat BPs cannot be processed to obtain usable objects. Under these circumstances, the only possibility is compounding them with other polymeric materials to obtain processable blends. This has indeed been achieved exploiting the solubility properties of BPs and the above polyethylene copolymers in miscible hydrophilic solvents, reacting the BPs and the copolymer in solution, and casting the reaction product from the solvent.

Another reason for the manufacture of the above BPs-containing composites is that the BPs molecules keep some of the mechanical stiffness typical of the parent native lignin. Mechanical stiffness may enhance the capacity of the film to save its original shape when subjected to mechanical stress. However, it will also decrease the film flexibility and elasticity. Thus, in the BPs composites, the polyethylene copolymer is necessary to provide the required property of mechanical flexibility and processability. On the other hand, 2–10% content of BPs filler enhances the film mechanical strength without compromising critically the desirable properties of the synthetic polymer. Moreover, the solubility properties of both the synthetic polyethylene copolymer and BPs in different miscible solvents allow the processability of their mixtures by solvent casting (Franzoso et al., 2015a, 2016).

So far, raw PHT plants have not been considered as potential fillers for the manufacture of composite plastic films using the solvent casting technique, due to their poor solubility properties and to the presence of the recalcitrant native lignin. However, most recently, Nisticò et al. (2016) have reported that EVOH-BPs blend films can be obtained also by single-screw melt extrusion. This work was carried out with some BPs obtained by hydrolysis of fermented municipal kitchen wastes. It evidenced some important facts. First, it must be considered that all BPs and their sourcing materials do not have melting properties (Franzoso et al., 2015a, 2016). They are stable up to 220 °C. They decompose at higher temperature without melting. Nevertheless, the possibility of processing by single-screw extrusion the EVOH-BPs mixes investigated by Nisticò et al. (2016) prospected that, by the same process, composites films might be obtained also from EVOH-PHT mixes. Second, for 2–10 wt % BPs content in the blend mix, no significant or critical deterioration was found for the mechanical properties of the blend compared to the neat EVOH film (Franzoso et al., 2015a, 2016; Nisticò et al., 2016). This implied that important cost and environmental benefits could be attained by manufacturing composites. They would stem from substituting part of the synthetic polymer with a low cost biomaterial derived from renewable source, while still maintaining the same mechanical properties of the neat synthetic polymer.

For the case study of the above BPs from fermented urban biowastes (Nisticò et al., 2016), cost benefits can be readily appreciated. Indeed, poly vinyl alcohol-*co*-ethylene is a special high cost polymer, with a market price (http://alibaba.com/ Alibaba.com, 2017) of about 6 €/kg. The BPs production cost is estimated 0.1–0.5 €/kg (Montoneri et al., 2011). It arises mainly from reagents and energy consumption by the hydrolysis of the sourcing biowaste. By comparison, the PHT plants are not processed chemically and do not require energy to drive a chemical reaction. Thus, even higher cost reduction and environmental benefits are potentially attainable by using the collected, not chemically processed PHT plants material as fillers to manufacture the EVOH composites.

In order to evaluate the feasibility of the above option, the present work reports not only the performance of the EVOH-PHT blend films, but also its comparison with the performance of the previously reported EVOH-BPs blend films (Nisticò et al., 2016) that were obtained under the same conditions.

2. Methods

2.1. Starting materials, films preparation and chemical analyses

Post-harvest tomato (PHT) plants (Lycopersicon Esculentum Cv. Naomi F1) and commercial EVOH pellets (Soarnol by Nippon Gohsei Europe GmbH) were available from previous work (Franzoso et al., 2015a,b, 2016). The PHT plant material was analyzed for its content of ash, elemental C and N, and C types and functional groups, according to previously reported methods (Franzoso et al., 2015a, 2016; Nisticò et al., 2016; Evon et al., 2017). The chemical compositions of both BPs and PHT were also analyzed on a macroscopic scale. This included contents for moisture, cellulose, hemicelluloses, lignin and water-soluble components. The moisture content was determined according to ISO 665:2000 (ISO, 2000). The cellulose, hemicelluloses and lignin contents were determined by the use of the acid detergent fiber-neutral detergent fiber (ADF-NDF) method of Van Soest and Wine (1967, 1968). Similarly, the water-soluble components were estimated by