Biochar as a sustainable alternative to carbon black in agricultural mulch films

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Agricultural mulch films (AMFs) are inexpensive, easy to use, increase crop yield, and diminish the use of pesticides and herbicides. However, the traditional plastic material used for AMFs is low-density polyethylene (LDPE), which creates additional costs due to disposal fees and additional labor (Madrid et al. 2022). Poly (butylene adipate-co-terephthalate) (PBAT) is a biodegradable polymer that has attracted attention due to its soil degradability, ductility and good processability to replace conventional plastics in agricultural applications (Kyrikou and Briassoulis 2007).

The key properties of AMFs are mechanical (tensile strength and tear resistance) and opacity, needed to endure the laying process and block light, thus suppressing weed growth. Carbon black (CB), a petroleum-derived filler, is often used to increase the opacity of these films (Botta et al. 2021; Kane and Ryan 2022; Zhao et al. 2022). Recently, biochar (BC), a carbon-based by-product of thermochemical conversion of organic waste, known for its soil amendment qualities, has been proposed as an alternative to CB as a plastic filler. Our previous work demonstrated BC as an effective processing additive for PBAT films (Hernandez-Charpak et al. 2022) and has been proposed as a sustainable alternative for CB in plastics (Kane and Ryan 2022; Botta et al. 2021). This study will present a comprehensive life cycle assessment (LCA) and techno-economical analysis (TEA) to demonstrate the sustainability of BC versus the conventional additive, CB.

The LCA will follow ISO standards 14040 and 14044, using an experimentally defined functional unit. The TEA will follow published methods applied to pyrolysis systems for organic waste to biochar conversion (Rowles et al. 2022; Phillips et al. 2018; Cisse et al. 2022; Haeldermans et al. 2020). PBAT films with nominal thickness of 50.8 µm (2 mils) were manufactured with CB (KetJenBlack EC-600JD) at 0%, 2% and 4% by mass, on a conical twin-screw extruder with a cast film attachment (CWB Brabender). Other PBAT films with similar thicknesses filled with commercial BC (Aries Clean Technologies) were manufactured at 2%, 4%, 6% and 8% by mass. On all films, mechanical (ASTM D886, D1922 and D3420), thermal (differential scanning calorimetry, DSC and thermogravimetric analysis, TGA) and opacity (Techkon Spectrophotometer) characterizations were performed.

Results suggest that a functional AMF can be manufactured using BC as a filler. However, there is a tradeoff, and a higher loading is needed to achieve equivalent properties to CB films, which aligns with previous literature (Botta et al. 2021). Degradation properties showed no statistical differences as seen in the TGA results; however significant differences were observed in the nucleation ability via DSC. The cold crystallization temperature (T_{CC}) is affected by both additives, as seen in Figure 1. T_{CC} appears to stagnate with increasing BC content, without reaching the levels of the films containing CB.

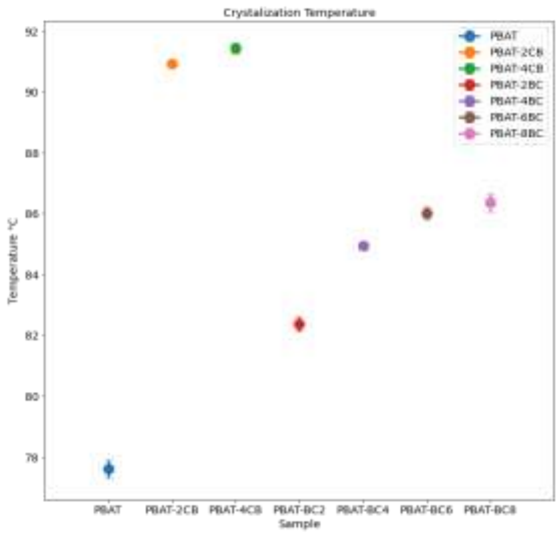

Figure 1. Cold crystallization temperature during the cooling cycle of the DSC analysis.

Our film extrusion produced films with thicker edges, allowing us to evaluate the effect of thickness on opacity for each concentration of BC. Figure 2 shows the opacity for the different concentrations of BC at different thicknesses and compares them to the films with CB. Field work from our group has allowed us to determine that an opacity of 75% is enough to restrict weed growth. Using opacity values above the threshold as our functional unit, we can compare the PBAT 2% weight CB as industry standard with different PBAT-BC concentrations and thickness that go beyond the threshold shown in Figure 2.

This work is in progress, more specifically the life cycle inventory of the CB production and of the BC production, and a thorough uncertainty analysis for both. It is becoming clear that thickness, a factor not considered in the current literature (Botta et al. 2021; Zhao, Wang, and Liu 2022), is a key variable to assess the sustainability of an opacity filler, specifically economic sustainability.

Preliminary results suggests that BC affects the intrinsic properties of PBAT in a similar way as CB, but not with the same effectiveness and dispersity. This agrees with the work of (Bélanger et al., 2023). However, the environmental and economic aspects are key sustainability indicators that might overcome the lesser performance of BC and position it as a sustainable alternative to CB.

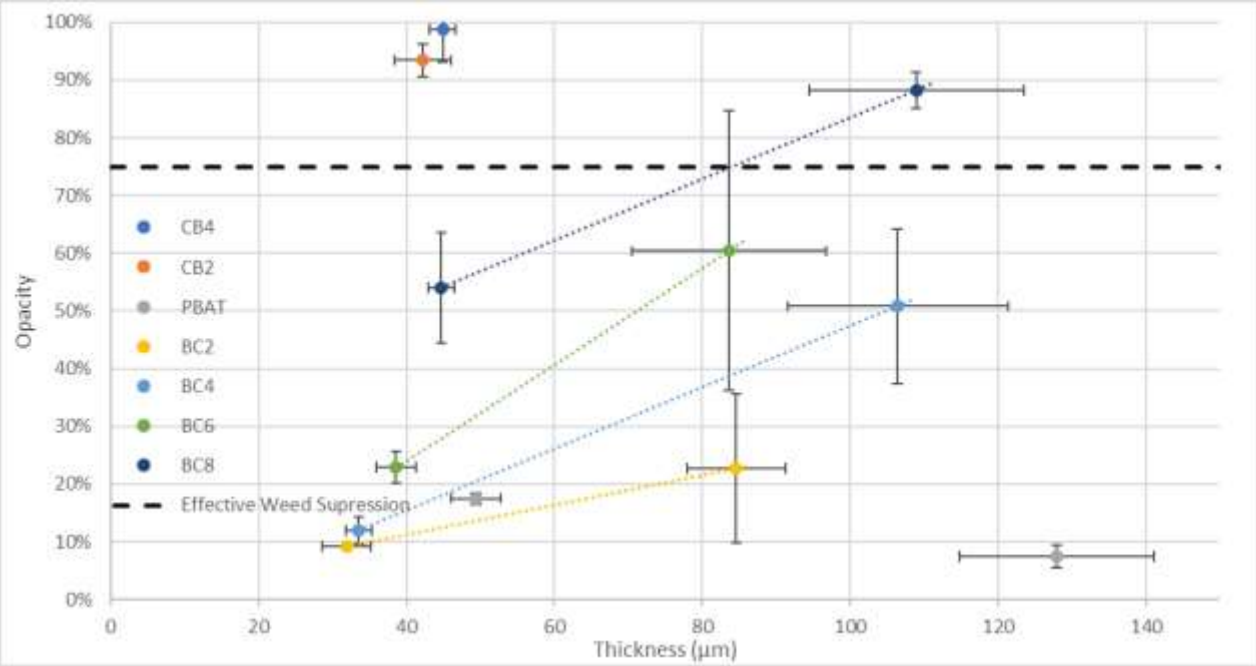

Figure 2. Opacity for PBAT films with different concentration of BC and CB fillers, at different thicknesses.

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