Biochar

A Sustainable Organic Fertilizer within the Framework of Circular Economy and Closing the Recycling Loop

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Background

Despite efforts to become more self-sufficient, the Gulf Cooperation Council (GCC) countries still depend on food imports, albeit to varying degrees, mainly driven by extreme climatic conditions. To address this situation, Qatar has, for instance, established a comprehensive food security strategy, resulting in greater self-sufficiency in many agricultural products. These initiatives align with Qatar's National Food Security Strategies (2018–2023; 2024-2030) and Qatar National Vision 2030. Accordingly, climate-controlled greenhouse farming has been playing an essential role in increasing local food production to cope with the extended hot and dry season conditions of Qatar. To this end, the land surface covered by greenhouses in Qatar has increased to 666 hectares (ha) in 2023 compared to 300 ha in 2018.

In addition to vegetable crops, greenhouse operations also generate around 15 tons of plant residues per hectare annually. As such, it is estimated that Qatar's greenhouse activities generate approximately 10,000 tons of plant residues per year, which constitute an environmental issue if unsustainably managed by burning or landfilling. On the other hand, these organic residues may serve as a valuable feedstock for biochar production, for instance, which considerably reduces waste volume and greenhouse gas (GHG) emissions while improving crop production.

Biochar is a porous carbonaceous solid that can be produced from various biomass waste sources, including agricultural organic residues, forestry byproducts, animal manures, and municipal solid waste. Pyrolysis is the most widely used method for biochar production. It involves the thermal decomposition of organic materials at temperatures varying between 250 and 900°C in the absence of oxygen, breaking down biomass into bio-oil, gases, and charcoal. The stable chemical structure of biochar, large specific surface area, high carbon content, and cation exchange capacity make it a versatile material with sustainable applications in various fields. Additionally, biochar contains some essential plant nutrients like potassium, sodium, magnesium, calcium, copper, zinc, and iron, which make it suitable for agricultural applications. By and large, biochar production from agricultural residues has tremendous agri-environmental benefits as compared to using chemical fertilizers or other unsustainable agro-chemicals.

The use of biochar as an organic fertilizer in agriculture has seen greater focus because it simultaneously reduces the carbon footprint and improves the physical, chemical, and biological properties of soil and hydroponic substrates, resulting in more sustainable crop production. More precisely, biochar application increases water and essential plant macronutrient retention, making it highly beneficial in arid regions characterized by limited water supplies, high evapotranspiration rates, and degraded soils. In this regard, recent efforts have focused on biochar modification to further enhance the physicochemical properties and adsorption capabilities using various methods. Biochar modification aims to either increase its surface area or to improve its surface characteristics and reactivity.

Research procedures

The research study aimed to transform agricultural wastes generated in Qatar into modified biochars to enhance local greenhouse production in the framework of the circular economy concept. This was in line with Qatar National Food Security Strategies as well as Qatar University Research Priorities (Water and Food Security-Resource Sustainability Pillar). The feedstock utilized for biochar production consisted of a 1:1 mixture of two locally generated agricultural residues, namely, lignocellulosic biomass and animal manure. The synthesis of the magnetic biochar (MBC) was performed using the co-precipitation method with iron salts. The impregnation of the magnetic biochar with phosphorus (P-MBC) was carried out as a second step modification by adding disodium phosphate. Then, both magnetic biochar forms (MBC and P-MBC) were added to the cocopeat substrate to grow cherry tomato in the greenhouse of the Center for Sustainable Development for an entire cultivation cycle using different application rates (Figure 1).

Figure 1: Tomato cultivation inside the greenhouse of CSD at QU.

Key findings

• Both modified biochars (MBC and P-MBC) were deeply characterized for their physico-chemical properties by using advanced techniques of surface scanning and elemental mapping. Accordingly, XRD analysis revealed the presence of magnetite on the surface of both biochars, while FT-IR and EDX techniques confirmed the successful impregnation step by detecting the presence of phosphorus and phosphorus-containing groups in the P-MBC sample.

• The cultivation cycle of cherry tomato inside the greenhouse lasted 120 days after transplanting. All biochar treatments enhanced plant biomass with respect to the untreated control, along with treatment MBC added at 2%, showing the highest shoot fresh and dry weights. Moreover, biochar application improved cumulative tomato fruit yield compared with the control, with the highest production recorded under the P-MBC treatment at a 1% application rate, resulting in an approximate 62% increase in yield (Figure 2). Likewise, biochar application positively increased total sugar content in tomato fruits compared to control plants.

Perspectives

This study examined the conversion of Qatari organic agricultural residues into modified biochars through magnetization and phosphorus impregnation to serve as a substrate conditioner in the framework of the circular economy and zero-waste principles. Outcomes indicated that the most significant effect of magnetic biochar addition was the improvement of tomato fruit yield and sugar content with respect to control plants. Moving forward, there are several areas where further research could significantly advance this field of investigation. First, examining the nutrient adsorption/release kinetics of these modified biochars is needed to understand the contribution of magnetization and phosphorus impregnation to the sought-after property of controlled nutrient release after application. Additionally, exploring other abundant agricultural residues in Qatar as potential feedstocks for biochar production could reveal ways to enhance the beneficial properties of biochars for soil or greenhouse substrate enhancement, and consequently, local food security improvement.

Figure 2: Control and treated plant appearance during the full production stage.