PRODUCTION AND DEVELOPMENT OF BIODEGRADABLE PLANT GROWTH MEDIA FROM AGRICULTURAL RESIDUES USING A REDESIGNED HYDRAULIC PRESS

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Abstract
Polymer-based plastic materials derived from fossil fuels are widely used in various sectors, particularly agricultural production; however, this leads to serious environmental pollution problems. The increase in solid waste, particularly caused by plastic-based seedling and plant growing media, contradicts sustainable agriculture goals. This study aimed to produce biodegradable growing media from organic waste such as agricultural harvesting and threshing waste and poultry litter using square molds. The production process was carried out using a computer-controlled, 100-ton capacity hydraulic press, which used square molds. The resulting products were subjected to various tests for soil solubility, physical strength, and environmental compatibility. The study aimed to contribute to sustainable agricultural production systems by presenting an innovative approach to reducing the use of fossil-based plastics.

Key words: *agricultural waste; poultry litter; biodegradable material; square mould;, hydraulic press.*

INTRODUCTION

The vast majority of plastics are derived from petroleum-based sources, and these polymeric materials pose significant environmental challenges due to their persistence as waste *(Emad et al., 2011; Reddy et al., 2013)*. Growing environmental concerns worldwide highlight the imperative to establish sustainable production frameworks that mitigate ecological impact *(Akinci et al., 2008; Bilgili et al., 2023)*. The strategic utilisation of organic wastes, particularly those originating from the agricultural sector, plays a critical role in mitigating environmental pollution while enabling the production of value-added outputs aligned with circular economy principles. Transforming agricultural by-products into biodegradable materials yields multifaceted benefits, including improved waste management, enhanced soil health, and increased resource efficiency *(Tabasaran, 2018; Sertgümeç et al., 2021)*.

Turkey's extensive agroecological diversity enables a broad spectrum of agricultural production; however, this process results in the generation of millions of tons of agricultural waste annually. According to data from the Turkish Statistical Institute *(TÜİK)*, the volume of waste arising solely from plant-based production is projected to exceed 22 million tons by 2024 *(TUİK, 2024; Türkiye Ministry of Agriculture and Forestry, 2025)*. A substantial proportion of these agricultural wastes are either incinerated or indiscriminately discharged into the environment, practices that not only exacerbate greenhouse gas emissions but also pose serious threats to soil and water resources.

In recent years, numerous studies have been undertaken to explore alternative utilization pathways for agricultural wastes *(Lligadas et al., 2013)*. The utilization of square molds to convert agricultural residues into biodegradable substrates represents an environmentally sound and economically feasible approach to sustainable cultivation systems *(Demirel et al., 2025)*. These types of growing media are particularly utilized in the cultivation of seedlings and ornamental plants; their capacity to be directly planted into the soil not only minimizes reliance on plastic containers but also enhances soil organic matter through natural decomposition *(Sugasit, 2011; Gramlich et al., 2010; Olgaç et al., 2025)*. The intensification of environmental issues, such as diminishing fossil fuel reserves and elevated greenhouse gas emissions, has prompted significant interest in the design and synthesis of sustainable polymeric materials *(Chieng et al., 2014)*. Currently, the most prevalent polymers are increasingly being produced from renewable feedstocks such as vegetable oils and bio-based precursors, reflecting a shift toward sustainable material developments *(Gramlich et al., 2010; Sawai et al., 2002; Gupta et al., 2007; Xiong et al., 2013; Chieng et al. 2014)*.).

Square molds employed in the fabrication of biodegradable growing media facilitate the compaction of agricultural residues into a uniform and mechanically stable form. The quality of the final product is significantly influenced by key process parameters, including pressing pressure, moisture content, fiber length, and the type of binding agents used. Furthermore, the agricultural wastes utilized in this context—such as wheat straw, corn cobs, sunflower husks, fruit pulps, and poultry manure enable the valorization of region-specific biomass resources.
This approach not only promotes environmental sustainability but also fosters rural development. The 2024 Strategic Plan of the Ministry of Agriculture and Forestry emphasizes key objectives such as the utilization of idle agricultural lands, the advancement of organic farming practices, and the widespread implementation of zero-waste policies. Within this framework, the development of biodegradable growing media is expected to generate new income streams for local producers while supporting the transition toward environmentally responsible production models. This study will provide a detailed examination of the technical aspects of the production process, the characteristics of the input materials, and their environmental implications. Moreover, the reliance on fossil-based plastic materials in plant cultivation particularly in greenhouse operations will be reduced, thereby contributing to the mitigation of environmental pollution.

MATERIALS AND METHODS

This study aimed to fabricate square plant growth media using a hydraulic press with a pressing capacity of 100 tons. Accordingly, the design criteria for the molds to be integrated into the production process were meticulously defined, taking into account various engineering parameters such as mold shape integrity, structural durability, manufacturing precision, and material compatibility. Based on these criteria, detailed three-dimensional models of each mold were developed using Computer-Aided Design *(CAD)* software. The technical drawings comprehensively illustrate critical production-related elements, including geometric specifications, connection interfaces, manufacturing tolerances, and assembly feasibility. These drawings are presented in Fig. 1.

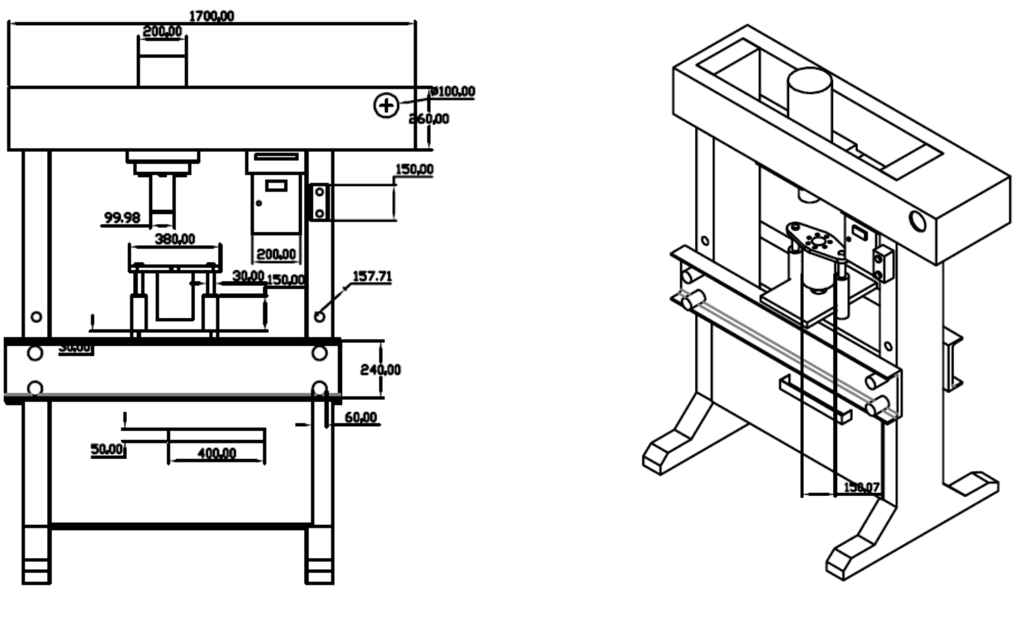

Fig. 1a General view and dimensions of the hydraulic press

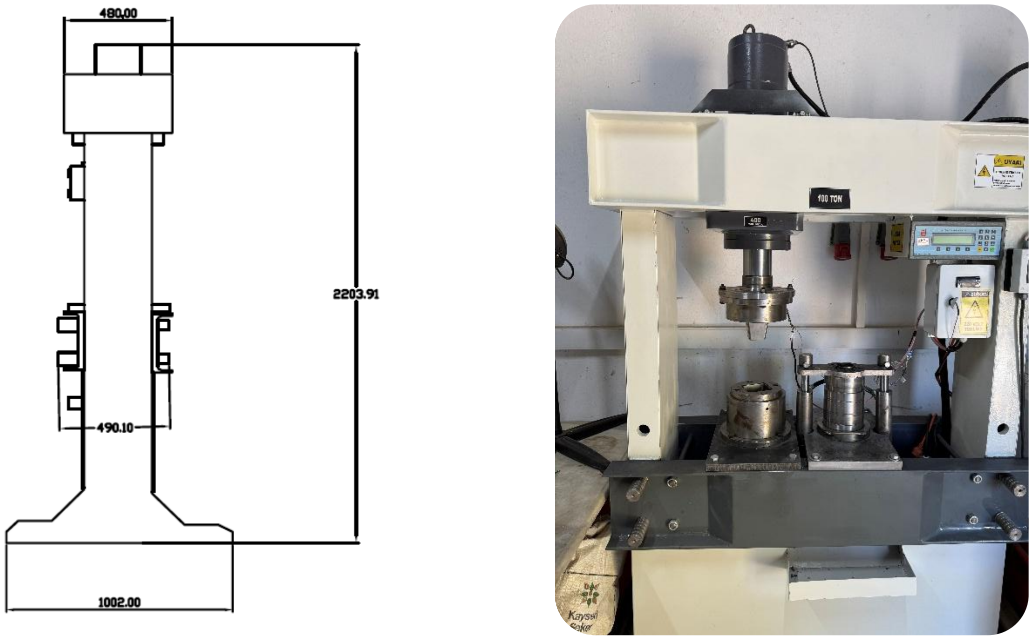

Fig. 1b General view and dimensions of the hydraulic press

RESULTS AND DISCUSSION

In the initial phase of the redesign and manufacturing process, new design criteria were meticulously established for both the press system and the molds to be integrated, ensuring that the 100-ton capacity hydraulic press could operate with optimal efficiency and reliability. Based on these criteria, high-strength steel grades such as Sd52 and Sd4140, along with other suitable engineering materials, were selected to meet the structural performance requirements. The procurement of these materials was initiated concurrently, followed by precision cutting and shaping using CNC machining in strict accordance with the CAD design specifications. The fabricated components were assembled using appropriate welding techniques to construct the main body of the press. During the assembly stage, the press structure and mold systems were integrated into a unified framework, after which the core hydraulic components including cylinders, pumps, and valves were carefully installed *(Fig. 2)*. Upon completion of the installation, leakage and pressure tests were conducted to verify the safe and stable operation of the hydraulic system. Subsequently, the fully assembled press and mold system underwent a series of load and performance tests to assess its structural integrity and operational efficiency under varying conditions.

Fig. 2a Views from the hydraulic press assembly phase

Fig. 2b Views from the hydraulic press assembly phase

The structural integrity of the growing media produced from molds is closely linked to the physical durability of the materials used, which must retain their form while simultaneously offering moisture and air permeability conducive to plant development *(El-Sayed et al., 2025)*. Additionally, maintaining shape and dimensional stability is essential for ensuring both functional performance and user practicality *(Anirudh et al., 2024)*. Achieving growing media that fulfill these criteria necessitates a highly meticulous and multi-stage production process *(Harahap et al., 2025)*. In the initial phase, the chemical and mechanical properties of the input materials were carefully selected, followed by appropriate preparation procedures. For applications demanding high mechanical strength, materials with superior wear resistance were prioritized, and their performance was further enhanced through heat treatment processes aimed at increasing hardness. To improve the surface quality of the final product and minimize frictional forces during molding, the inner and outer surfaces of the molds were refined through coating or polishing techniques *(Fig. 3)*.

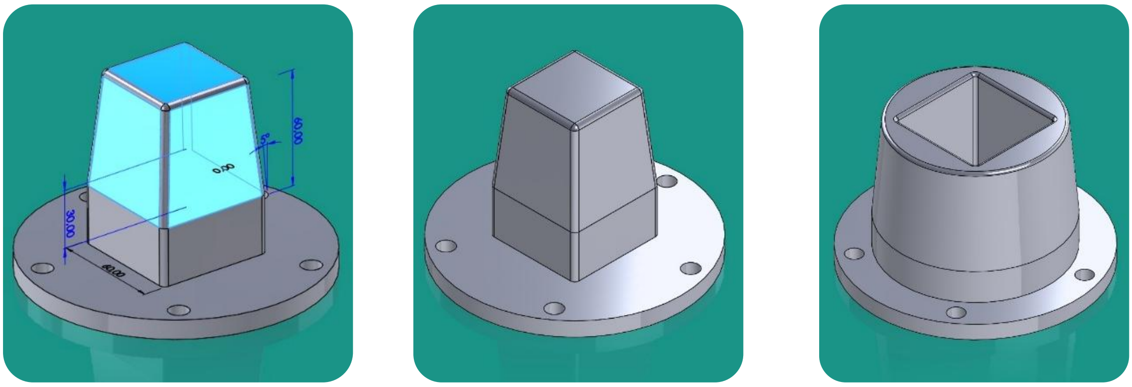

Fig. 3 Dimensions and appearances of square molds

A heating system was integrated into the molds to facilitate the rapid and efficient release of the formed material from the designed mold cavity. This system enables the mold temperature to be elevated up to 200°C, thereby enhancing the demolding process and overall production efficiency *(Fig. 4)*.

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Fig. 4 Mold heating system

Pressing Process

The hydraulic press operates autonomously based on pre-programmed parameters for pressure level and application duration, with system settings precisely configured via the operator control interface. Designed with a pressing capacity of 100 tons, the press facilitates the formation of the desired geometric configuration and material density by uniformly compacting the production medium under high pressure. Achieving a void-free internal structure and consistent density distribution throughout the material volume is essential for ensuring production quality. Accordingly, critical operational parameters including pressure, temperature, and stroke position are continuously monitored by advanced sensor systems and regulated in real time through integrated control software *(Fig. 5)*.

Fig. 5 Pressing process

Extraction and Drying

Upon completion of the pressing process, the molds were carefully opened, and the formed plant growth media were extracted without any structural deformation. The resulting products were then transported to the designated drying area using appropriate handling techniques to maintain their physical integrity. The drying procedure was conducted with precision to enhance the mechanical strength of the products, optimize material hardness, and improve resistance to environmental factors. This step also ensured the suitability of the products for long-term application conditions *(Fig. 6)*.

Fig. 6 Square mold plant growing medium

Following the drying process, the fabricated plant growth media underwent a series of quality control assessments. These evaluations focused on key performance indicators, including density distribution, structural integrity, and homogeneity. Only those products that met the established criteria for reliability, durability, and functional suitability were approved for release from the system.
Despite the system's 100 ton pressing capacity, structural issues emerged during the later stages of the production process. These complications were primarily attributed to stress accumulation and uneven load distribution, which had not been adequately anticipated during the preliminary design phase. Such deficiencies posed significant risks of deformation and crack formation, particularly in the main load-bearing structure. Consequently, structural enhancements in specific components became imperative. Based on comprehensive technical analyses conducted in collaboration with the manufacturer, it was concluded that both material substitutions and design modifications were necessary for several critical elements. The implementation of these changes including the fabrication of new components and their integration into the system required more time than initially projected. Upon completion, additional testing and rigorous quality control procedures were performed to validate the effectiveness of the applied improvements.
Furthermore, following the commissioning of the system, several software-related malfunctions were identified within the automation program. These errors led to the misinterpretation of sensor data, resulting in the execution of incorrect commands by certain press functions. Consequently, the operational efficiency of the machine was adversely affected, and various disruptions in system performance were observed.
To identify and resolve the software-related issues, a comprehensive review process was initiated in collaboration with the software development team. The codebase was meticulously examined line by line, and algorithms with a high likelihood of error were optimized. Revisions were also implemented in data processing methodologies to enhance accuracy. Furthermore, additional security protocols and error correction mechanisms were integrated into the software to promote more stable system operation and to mitigate the risk of similar malfunctions in the future.
Upon completion of the comprehensive improvement process, all machine functions were systematically retested. Extensive testing procedures were carried out to confirm that the system operated safely, reliably, and with high efficiency across a range of operational scenarios.

CONCLUSIONS

The design activities undertaken in the development of redesigned machines necessitate a comprehensive approach encompassing numerous technical specifications and complex engineering procedures.

Within this framework, the selection of appropriate materials is of paramount importance to ensure both operational efficiency and extended service life. Material choices must be evaluated not only for their mechanical properties but also in terms of production cost and supply chain feasibility factors that are critical to the overall success of the project. The manufacturing phase involves high-precision processes, wherein each component is fabricated in strict accordance with the corresponding technical drawings. Given that any deviations during production may adversely impact both product quality and process integrity, rigorous quality control mechanisms have been implemented to maintain consistency and reliability.

Throughout the design and planning stages, comprehensive engineering analyses, numerical simulations, and load distribution modeling were conducted to enhance the machine's functionality and overall system efficiency. Following the manufacturing phase, each component was individually tested to verify that the machine fulfilled its intended functions within the integrated system framework. Where necessary, final performance was further optimized through targeted adjustments.

The successful execution of all technical and structural processes enables the machine to meet the performance criteria established within the scope of the project, thereby contributing directly to its overarching objectives. Reliable system operation facilitates the consistent mass production of plant growth media with the desired quality and specifications, ensuring both the sustainability of the project and the effectiveness of its implementation.

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