

Biljni proteini kao sastojci nosača za primjenu u proizvodnji kultiviranog mesa: pregledni rad

SAŽETAK

Ovaj rad daje pregled trenutnog stanja razvoja nosača temeljenih na proteinima biljnog podrijetla za primjenu u proizvodnji kultiviranog mesa. Poseban naglasak stavljen je na izvore proteina iz najvažnijih poljoprivrednih kultura kao i metode njihove prerade u funkcionalne biomaterijale. U radu se raspravlja kako različiti postupci ekstrakcije proteina i nove tehnologije utječu na čistoću, funkcionalnost i prikladnost proteina za izradu nosača. Trenutno korištene metode izrade nosača poput ekstruzije, liofilizacije, elektroispredanja, hidrogelova i kompozitnih polimernih sustava istražuju se s obzirom na njihovu sposobnost stvaranja trodimenzionalnih nosača prehrambene kvalitete s odgovarajućim mehaničkim svojstvima, poroznošću i kompatibilnošću sa stanicama. Također se navode ključni izazovi i budući smjerovi istraživanja, uključujući optimiranje nosača na bazi biljnih proteina za poboljšanje prijanjanja, proliferacije i diferencijacije mišićnih stanica, kao i potreba za poboljšanjem reproducibilnosti postupka te povećanja obujma proizvodnje. Sveukupno, ovaj rad ističe snažan potencijal materijala temeljenih na biljnim proteinima u proizvodnji većih količina kultiviranog mesa uz istovremeno smanjenje negativnog utjecaja na okoliš i oslanjanja na komponente životinjskog podrijetla.

Ključne riječi: kultivirano meso; mišićne stanice; biljni protein; izrada nosača; održivost

Conclusion

Scaffolds play a fundamental role in cultivated meat (CM) technology by providing a structural framework that supports cell attachment, proliferation, and organization, thereby influencing the texture and architecture of the final product. Their importance lies in their ability to provide desired structural characteristics while allowing protein content and other nutritional components to be adjusted independently of texture. The fabrication method is therefore critical in determining both the functional performance and commercial feasibility of plant protein-based scaffolds.

Among the currently investigated approaches, hydrogel molding combined with physical or chemical crosslinking and simple post-processing techniques such as thermal setting or freeze-drying is one of the most widely adopted strategies. This approach offers relatively low processing complexity, cost-effectiveness, and compatibility with food-grade manufacturing, particularly for water-soluble proteins such as soy and pea proteins. In contrast, more hydrophobic proteins, including zein and peanut protein, and to a lesser extent chickpea protein, are well suited to fiber-forming techniques such as electrospinning, which provide greater control over scaffold architecture and surface characteristics relevant to muscle cell alignment and differentiation.

Zein also exhibits favorable rheological properties, including high solution viscosity and shear-thinning behavior, making it suitable for 3D-printed scaffolds for structured CM products. Blending plant proteins with food-grade polymers such as alginate, cellulose derivatives, or pectin can improve print fidelity, shape retention, and structural stability, while the incorporation of gelatin may enhance cell attachment. Extrusion-based fabrication using soy-, wheat-, and chickpea-derived proteins is also gaining attention because of its scalability, ability to produce aligned and mechanically robust structures, and reduced dependence on supporting polymers or crosslinking agents. Microcarrier-based scaffolds produced through emulsification or electrospraying represent another promising approach, particularly for non-structured CM products.

Among plant proteins, pea protein currently represents one of the most promising candidates for industrial-scale CM scaffolds because of its availability, cost-effectiveness, established food-grade production, and favorable functional properties, including gelation, water retention, and tunable rheological behavior. Although pea protein alone may have limitations in mechanical strength and cell-interactive properties, these limitations can potentially be addressed through blending with other food-grade polymers or bioactive components. Its versatility and compatibility with hydrogel-based systems make pea protein particularly suitable for structured CM applications, including porous scaffolds produced from cooled or freeze-dried hydrogels and bioinks for 3D-printed products.

Overall, plant protein-based scaffolds offer considerable potential for the development of scalable, food-compatible, and nutritionally relevant scaffolding systems for CM production. Their functional diversity and compatibility with multiple fabrication techniques provide opportunities to tailor scaffold architecture, mechanical properties, and nutritional characteristics according to the requirements of different cultivated meat products.

Future Challenges and Prospects

Despite the considerable potential of plant protein-based scaffolds, several challenges must be addressed before their widespread industrial application in cultivated meat production. One of the major challenges is achieving sufficient cell adhesion using scaffolds composed solely of plant proteins. Although animal-derived components such as collagen, gelatin, and fibrinogen provide excellent cell-supportive properties, their use is inconsistent with the animal-free objectives of cultivated meat. Recombinant proteins and fungal-derived materials therefore represent promising alternatives for developing animal-free, cell-supportive scaffolds [91,92].

Another important challenge is balancing scaffold performance with industrial scalability and production costs. Successful scale-up will require consideration not only of manufacturing feasibility and economic viability but also of resource efficiency, environmental sustainability, and life-cycle impacts. The development of scalable fabrication processes that maintain appropriate structural, mechanical, and biological properties will therefore be essential.

The sensory characteristics of plant protein-based scaffolds also require further attention. Many plant proteins, particularly soy and pea proteins, can contribute grassy, beany, or nutty flavor notes that may negatively affect the sensory acceptance of cultivated meat. These off-flavors are primarily associated with lipid oxidation products and volatile compounds naturally present in plant materials and may persist during scaffold fabrication and tissue cultivation. Potential mitigation strategies include the use of highly purified protein isolates and extraction processes designed to minimize oxidation. Less flavor-active proteins, such as zein, as well as flavor-masking ingredients, fat-containing cultivated cell biomass, and post-processing flavor optimization, may also help reduce scaffold-derived off-notes and improve the sensory quality of the final product [93].

Future research should also expand the range of plant protein sources used for CM scaffolds. The investigation of novel and underutilized plant resources is important for improving sustainability and reducing dependence on conventional protein crops. Leafy green plants are particularly promising because of their rapid growth, high biomass yield, year-round availability, and potential for valorization of agricultural biomass that is currently underutilized or treated as waste. Recovering proteins from these renewable resources could provide a sustainable source of scaffold materials while simultaneously adding value to low-cost plant biomass.

Finally, integrating proteomic analysis with economical processing strategies represents a promising direction for accelerating the development of cost-effective, nutritionally relevant, and cell-supportive plant protein-based scaffolds. Characterization of protein composition, molecular weight distribution, and functional domains can help identify proteins with desirable structural stability, digestibility, and bioactivity. Proteomic approaches may also reveal cell-adhesive sequences or functional motifs that promote cell attachment, proliferation, and differentiation. Such knowledge could reduce the need for extensive chemical modification and facilitate the rational design of plant protein-based scaffolds with improved biological functionality.

Future studies should therefore focus on optimizing plant protein composition, scaffold architecture, cell–scaffold interactions, sensory properties, scalability, and environmental performance simultaneously. Addressing these challenges will be critical for translating laboratory-scale plant protein scaffolds into commercially viable and sustainable CM production systems.