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Lab-Grown and Cellular Coffee

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Lab-grown coffee-produced through cellular agriculture-offers a promising alternative to traditional bean farming. By culturing coffee cells in bioreactors, researchers aim to reduce environmental impacts like water usage, deforestation and climate vulnerability. Early sensory panel's report smoky, burnt-sugar notes with comparable bitterness and acidity to conventional brews. Yet challenges remain: optimizing flavour, scaling production, regulatory clearance and balancing socio-economic consequences. This article synthesizes recent scientific literature, start-up initiatives and expert commentary to assess lab-grown coffee's potential and limitations.

Keywords: Cellular Agriculture, Lab-Grown Coffee, Bioreactor Cultivation, Sustainable Coffee Production, Coffee Innovation and Beanless Coffee Alternatives.

Introduction

Global coffee production is under strain due to climate change, land degradation and pest infestation. By 2050, up to half of current coffee-growing land may become unproductive. As demand continues to rise-expected to double by 2050 - innovative solutions are needed to ensure supply, reduce environmental harm and minimize socio-economic fallout. Cellular agriculture-growing plant cells in controlled bioreactors-offers a sophisticated approach to producing coffee without plantations, pesticides or deforestation. In Finland, VTT Technical Research Centre successfully cultivated *Coffea arabica* cell biomass, roast-tested it, and performed sensory analysis, establishing a proof of concept for lab-grown coffee.

The Science Behind Cellular Coffee

Culturing Coffee Cells in Bioreactors: VTT's process begins by sterilizing leaf tissue from *Coffea arabica* to initiate callus formation in a nutrient medium. After expansion, cells are transferred to progressively larger bioreactors for growth over approximately 2 weeks. Post-harvest, the biomass is freeze-dried, ground into powder, and roasted under various regimes to induce flavour compounds.

Flavour and Chemical Profile: Comparative chemical analysis reveals that roasted cellular coffee shares key sensory attributes with regular coffee-such as bitterness and acidity-but flavour compounds differ. Notably, typical Maillard reaction products like guaiacol and pyrazines (responsible for chocolate, caramel, nut-like aromas) are reduced or absent, while smoky and burnt-sugar notes dominate. Instrumental analysis confirms overlapping volatile profiles in broader aroma compounds.

Sensory Evaluation: A trained sensory panel at VTT found the cell-cultured brew to resemble traditional coffee, though lighter in roast character. Bitterness and sourness were comparable, but the aroma leaned toward smoky notes rather than the full-bodied roast profile expected from bean-grown coffee.

Environmental & Sustainability Potential

Reduced Land & Water Use: Growing coffee cells in bioreactors uses minimal land and recirculates water, eliminating runoff and irrigation waste—a total contrast to field cultivation that requires approximately 140 litres per cup—and conversion of forested land. The process also avoids pesticides and fertilizers common in conventional coffee farming.

Climate Resiliency: Because lab-grown coffee is not vulnerable to weather, pests, or temperature extremes, it offers greater supply stability amid climate disruptions threatening major producing regions like Brazil, Ethiopia and Colombia.

Carbon Emissions & Lifecycle Considerations: While lab-grown coffee could reduce deforestation and transportation emissions, its environmental benefits depend heavily on the energy source powering bioreactors. If renewable electricity is used, lifecycle impacts may be lower—but if not, gains could be negated.

Commercial Landscape & Start-ups

VTT's Commercial Vision: VTT estimates that with scale, production costs could become lower than cell-cultured meat, and anticipates regulatory approval (e.g. Novel Food in EU; FDA in US) within 4 years. Initial public surveys in France and Germany showed consumer willingness to trial cell-based foods—44-58% respondents expressed openness to cultured meat, implying crossover interest.

Beanless Coffee: Atomo and Compound Foods: Seattle-based Atomo Coffee produces “molecular” cold brew from date seeds, chicory, grape skins and caffeine—claiming up to 93 per cent less carbon emissions and 94 per cent less water use versus bean coffee. With over \$50 million in funding and a new roasting facility in Seattle, Atomo is positioning itself to scale toward price parity with premium coffee. Compound Foods—also in the US—is developing Beanless, fermentation-based coffee, starting with blends like Mocha-Java and targeting launch near 2025. Their process uses microbial fermentation and aims to mirror traditional flavour profiles using plant-based material sources.

Broader Industry Outlook: A growing wave of start-ups in the US, Singapore, Israel, and India are exploring lab-grown or Beanless coffee forms as part of a broader cellular agriculture boom in Europe and beyond.

Advantages & Limitations

Benefits

Sustainability: Reduced water use, land conversion, pesticide usage and transportation emissions.

Resilience: Protected from weather and climate variability.

Consistency & Design Flexibility: Flavour, caffeine content and aroma can be tuned through culture conditions and elicitors.

Limitations & Challenges

Flavour gap: Missing critical aroma compounds limits sensory parity with specialty bean coffee.

Caffeine content: Early bioreactor batches had significantly lower caffeine per gram (~0.22 mg/g vs 8.6 mg/g), though improvements possible by exposure to stimuli like light or aluminium salts.

Regulatory roadblocks: Must achieve Novel Food approval in Europe and FDA clearance in US before commercialization.

Societal impact: Potential disruption to livelihoods of millions of coffee farmers in developing economies.

Future Outlook and Research Directions

Flavor Optimization: Continued chemical and sensory research is underway to enrich aroma compound profiles *via* improved roasting protocols, elicitors and reactor conditions.

Scaling Production & Cost Reduction: Economies of scale could dramatically reduce costs-as seen analogously in cultured meat-a key step toward price competitiveness for cell-based coffee.

Life Cycle Assessment and Sustainability Validation: Detailed LCA studies are needed to quantify net environmental benefits under varying energy and resource profiles.

Regulatory & Social Integration: Navigating food regulations, building consumer trust and developing transition strategies with traditional producers-through partnerships and inclusive frameworks-will be essential.

Conclusion

Lab-grown coffee represents a ground-breaking shift in how coffee might be produced in a warming, resource-strained world. By cultivating coffee cell biomass in controlled bioreactors, it promises dramatic reductions in water use, land conversion and supply vulnerability. Early sensory evaluations are promising, though the flavour remains smoky and requires further refinement. The promise is clear, but challenges remain: improving aroma profiles, boosting caffeine content, earning regulatory approvals, scaling at affordable prices and managing socio-economic impacts on traditional producers. As research advances and start-ups scale-including VTT, Atomo Coffee and Compound Foods-the coming decade may reveal whether lab-based coffee becomes a sustainable complement-or even substitute-for bean-grown brews. Its success will depend on marrying technological progress with considerations of taste, ethics and equitable transition in the global coffee economy.

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