Plant molecular farming

Plant molecular farming is a form of alternative protein production that combines plant agriculture and techniques similar to those used in precision fermentation to enable the production of animal proteins (like dairy or egg proteins) in plants. This process allows the production of alternative proteins inside a plant using photosynthesis and well-established farming techniques.

Commercial landscape

Currently, 12 known companies are advancing this technology for the alternative protein sector. Here are a few examples of product approaches:

- **Forte Protein** and **Greenovation Protein** use plants to produce lactoferrin, casein, albumen, collagen, and myosin.
- **Miruku**, **Mozza**, and **Nobell Foods** produce animal-free dairy proteins for use in products like cheese, ice cream, and yogurt.
- **Tiamet Sciences** and **Bright Biotech** create growth factors for cultivated meat media and for medicine.
- **PoLoPo** and **Veloz Bio** are developing egg proteins.
- **Asterix Foods** and **Imagene** are applying the technology toward ingredient optimization for the alternative protein industry.

Nomenclature note: For consistency, we've repeatedly referred to this technology as "plant molecular farming" throughout this fact sheet and our State of the Industry Reports. However, like in any emerging industry, the language used to explain the technology, the terms adopted in the business landscape, and the terms eventually used for describing end products to consumers may vary and coalesce as the industry grows. Thus far, companies have used different terms to describe their products. For example, **Nobell Foods**, which uses this technique to make casein using soybean plants, describes their process as resulting in "plant grown proteins," and refers to their final product as "animal-free cheese," the same nomenclature often used by precision fermentation dairy companies to describe their products to consumers.

Investments

Plant molecular farming is a subsector of the alternative protein industry, with only 12 companies. As such, there is high variation in funding from year to year and funding totals from each year represent a small number of rounds.

	2017	2018	2019	2020	2021	2022
Invested capital	$25 MM	-	-	-	$118 MM	$15 MM
Deal count	1	-	-	-	8	7

In early 2023, **Moolec Science** became the first publicly traded plant molecular farming company, joining the small but growing list of publicly traded alternative protein companies. Moolec acquired **LightJump Acquisition Corporation**, a publicly traded special purpose acquisition company (or SPAC), through a reverse merger for $138 million. This resulted in the combined entity trading on the NASDAQ under the ticker symbol MLEC and MLECW beginning on January 3, 2023. As part of the transaction, the company received $10 million of development capital from undisclosed investors on the same date via a private placement.

The promise of plant molecular farming

Leveraging plants as recombinant protein hosts could offer a number of benefits, including the following:

1. **Plant molecular farming could occur on farms in open fields where allowed, and does not face the scaling challenges associated with large bioreactors.**

   This process could lead to lower inputs, increased production scale, and allow for harvest and process protocols similar to those established for plant-based protein ingredients. In 2022, **IngredientWerks** announced their spinout from AgriVida and plans to develop protein expression in row crops like *Zea mays* (corn). The idea is to leverage the mature processing infrastructure for crop starch and protein separation from row crops.

2. **Plant bioprocessing technology is mature and companies using this approach are taking advantage of that maturity to produce recombinant proteins in novel ways.**

   In 2022, **Nobell Foods** (formerly Alpine Roads) submitted a patent application foron transgenic plant production of recombinant casein/lactoglobulin (whey). Within that application, they demonstrate the fusion expression of casein and lactoglobulin that can then be cleaved after isolation. These technologies take advantage of plant expression systems to simultaneously make two major components of dairy protein—casein and whey.

3. **Gene expression regulation in plants is similarly complex to that in other multicellular eukaryotes.**

   Plant genes can have enhancer elements, promoters, and terminators. All of these elements afford the opportunity to tune and control gene expression that leads to protein production. In 2022, **Leaf Expression Systems LTD** applied for patent protection on their plant molecular farming expression vectors that include upstream and downstream elements designed to enhance protein yield. As plant transgenic approaches and gene expression systems improve, protein yields and plant molecular farming applications will become more widespread.

4. **Plants have a variety of tissues for protein expression.**

   Recombinant proteins could be produced in leaf, root, or seed cells. In 2022, **Core Biogenesis** applied for patent protection and raised $10.5 million to develop their system to express proteins in oilseeds to allow for a unique approach to downstream processing and protein purification to reduce costs and improve efficiency.

5. **These approaches are broadly applicable to crop improvement.**

   Carrot callus tissue can be fermented to produce protein such as brazzein using airlift vessels. Related, an LCA analysis published in 2022 showed that the environmental impact of plant cell culture is comparable to that of greenhouse agriculture. This technology can also be used for nutrition improvement in plants, for example, by introducing the vitamin D_3 biosynthesis pathway to tomatoes to biofortify fruit and leaf tissue with vitamin D_3.