



TECHNOLOGY DEVELOPMENT FOUNDATION OF TURKEY



PIONEER PROJECT PROGRAM ALTERNATIVE PROTEIN TECHNOLOGIES

DEEP DIVE STUDY - **SUMMARY**

April 2024



TTGV
**PIONEER PROJECT
PROGRAM**
#ClimatePioneer





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1. Introduction

The Technology Development Foundation of Türkiye (TTGV) has centred its focus on Climate Technologies since 2023 and aims to invest in pioneering, scalable, and reproducible projects in this field. In this context, a Venture Capital Investment Fund has been established, and the **“Pioneer Project Investment Programme”** has been launched. At the same time, the “Pioneer Project Early Stage Venture Development Program” has been launched as of 2024 to support early-stage technologies and ventures in the identified climate technology fields. To carry out a Deep Dive Analysis on selected prioritized climate technologies, TTGV collaborates with relevant domestic and international stakeholders to investigate the current status of these technologies. Subsequently, an informative report containing the findings of the deep dive analysis performed on the relevant technologies is prepared. This report reveals the basic information, assessments, insights, and stakeholder opinions on the investigated technology and includes related innovations under investigation, studies on investment, and feasibility by drawing up a project scenario. Additionally, during the study, researchers conducting work with early-stage technology potential and ventures/developers capable of demonstrating products/services are identified, contributing to the Pioneer Project Early-Stage Venture Development Program.

Within the scope of the TTGV Pioneering Projects Investment Programme, **“Alternative Protein Technologies”** was chosen as the subject of the IVth Deep Dive Analysis. In the period between November 2023 and March 2024, a comprehensive Deep Dive Analysis was carried out by contacting nearly 100 sector experts and organizations from Türkiye and abroad, in addition to examinations, to understand this subject first, which is undergoing a wide range of developments on a global scale, to analyze the current situation on the subject, to develop recommendations for our country and to create potential project

scenarios. **The Alternative Protein Deep Analysis Study** has been the most comprehensive and multidimensional Deep Analysis Study ever conducted due to the intricate relationship between human beings and food, the direct impact of alternative proteins on the lives of individuals, and the socio-cultural, socio-psychological, ethical, social and religious aspects of this issue. In this sectoral deep analysis study, the current food (especially protein) system has been analyzed, and in this context, problem definition, opportunities, and threats have been studied. Subsequently, the concepts of “alternative protein” and “new food” have been discussed, and alternative protein technologies have been evaluated in detail. Investments and legislation in this field in the world and in our country have been examined. Future tendencies in the sector, sector trends, and recent developments have also been discussed. In light of all this information, **the alternative protein issue has been strategically considered; recommendations have been made for Türkiye, and potential project scenarios have been created.**

Below, you can find summarized findings and evaluations of the results obtained in this study:

1. According to the data published by the United Nations (UN), the world population is estimated to reach 9.8 billion in 2050, followed by an increase in global demand for food products by 60% to 70%, and therefore, an increase in food-related emissions is expected. Especially in developing countries, the demand for animal products such as meat, eggs, milk, and dairy products is increasing due to rising income and supportive government policies [1-3].
2. It is determined that 26% of global greenhouse gas emissions originate from the food and nutrition value chain (crop agriculture, animal agriculture, supply chain) and 14.5% directly from the livestock sector. The amount of greenhouse gas emissions originating from livestock is higher than that from the entire transportation sector [4].
3. It is reported that 40% of methane (CH₄) emissions, whose global warming capacity is defined as 21 times higher compared to carbon dioxide (CO₂), originate from the agricultural sector and especially from enteric fermentation of ruminant animals and management of animal fertilizers [5].
4. It is stated that even if fossil fuel emissions were eliminated immediately, emissions from the global food system alone would make it impossible to limit global warming to 1.5°C and even more difficult to reach the 2°C target [6].

5. While the livestock sector utilizes 77% of the world's agricultural land, the ratio of the protein obtained from the sector to the total protein supply is 37%. More than 40% of agricultural water consumption is used in animal feed production. This leads to widespread water and soil pollution, habitat loss, and a reduction in biodiversity [7, 8].
6. The overuse of antibiotics in livestock farming (73% of global antibiotic sales) is considered to pose a significant risk to public health, and some livestock management practices are thought to increase the risk of zoonotic diseases. In addition, the current form of animal husbandry activities has negative impacts on animal welfare [9].
7. Animal husbandry activities are also an important source of income and living. In addition to being a significant part of nutrition, animal products have a social and cultural importance for many societies.

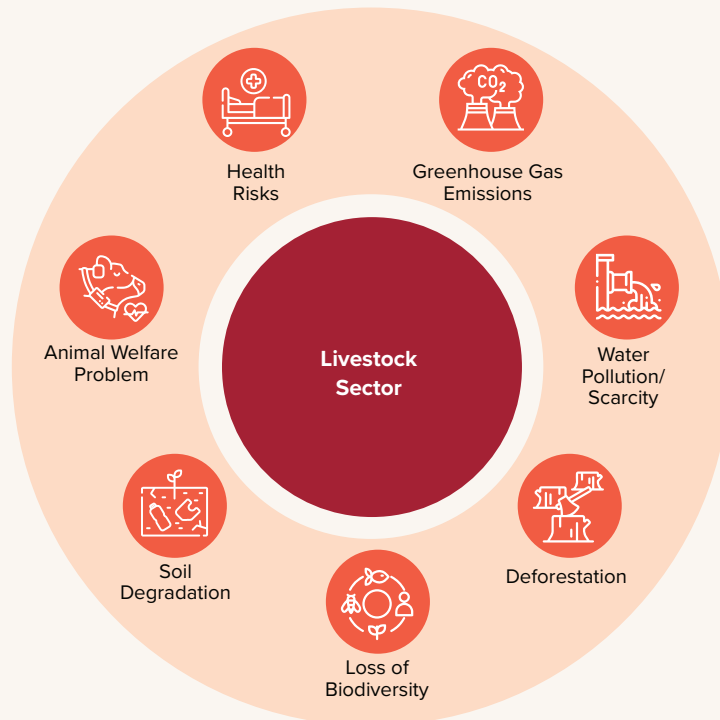


Fig. 1. Effects of Livestock Sector

8. Along with the increasing demand for food, changes due to climate change and the increasing frequency and severity of extreme weather events are threatening the sustainability of food systems and food supply security.
9. It became crucial to balance the complex and multifaceted impacts of the livestock sector and to ensure the equitable transformation of traditional food systems into sustainable food systems. In this process of transformation, in addition to more efficient and sustainable agricultural and animal husbandry practices (development of feed additives that reduce emissions, minimization of agricultural and food logistics, practices that prevent food waste and losses, etc.), efforts to develop **“alternative protein technologies”** for the production of new protein-rich human food and animal feeds are increasing.
10. **Alternative Proteins** are defined as plant-based proteins obtained from plant sources by protein extraction and isolation; cell-based proteins (cultured meat) produced by using animal cells in the laboratory environment; single-cell proteins (microbial proteins) produced by fermentation method by using microorganisms such as fungi, microalgae, bacteria, and yeast; target proteins obtained by precision fermentation, and proteins produced from other alternative sources (insects, jellyfish, microalgae and similar) (See Fig. 2).
11. Nevertheless, it is observed that terminology and concepts about alternative proteins are not fully established, and sometimes they even lead to confusion. This is based on the fact that alternative protein has a highly relative and flexible definition, and that this definition varies depending on geographical, cultural and societal (and even personal) contexts.
12. Compared to conventional animal protein production, alternative protein technologies have the potential to reduce agriculture-water use, greenhouse gas emissions, and consequently environmental pollution. For example, even in energy-intensive technologies such as the production of cultivated meat, it is estimated that there is a significant reduction in environmental impacts if renewable energy is utilized. There are ongoing life cycle analyses for new protein sources, and there is a need to improve these studies in order to provide more precise outputs.

Alternative Protein Technologies				
Source	 Stem cell	 Plant	 Bacteria  Fungi  Microalgae  Yeast	 Insect  Jellyfish  Macroalgae
Method	 Cultivation	 Traditional/ Grinding  Protein Extraction/ Isolation	 Fermentation	 Traditional/ Grinding  Protein Extraction/ Isolation
Output	 Cultivated Meat	 Plant-Based Protein	 Single Cell Protein/Target Protein	 Protein from Alternative Sources

Fig. 2. Alternative Proteins and Their Sources

13. In studies designed to understand the nutritional adequacy of alternative proteins and their effects on human health, it should be noted that proteins are primarily the building blocks of the body rather than energy sources; therefore, protein quality (or in other words, essential amino acid contents and bioavailability of alternative proteins - scores such as DIASS / PDCAAS) should be taken into consideration, and studies should be carried out by taking these parameters into account.
14. There are many criteria to be considered so that alternative proteins could become widespread and ensure their success:

Consumer Acceptance: For alternative proteins to be accepted by consumers, it is expected that the alternative protein products should have similar organoleptic properties such as taste, odour, texture, colour, and nutritional values as conventional meat. In addition, while some products are “over-processed”, the fact that they are over-processed makes consumer acceptance more difficult. Cultivated Meat and insect-based proteins, on the other hand, have reasons for not being accepted due to cultural and religious beliefs.

Development / Scale-up of Technologies: Although some products are tested and brought to market, development processes are still ongoing for many technologies. Beyond the development of technologies for laboratory/pilot scale, commercial scale-up for large populations, process optimization, etc. will be a challenging phase.

Cost of Production: Due to factors such as raw material costs, processing methods and scale-up, alternative protein products are currently more expensive than conventional food products.

Supply Chain Constraints: Providing a stable and sustainable source of raw materials, especially for producing plant-based proteins, is considered a significant challenge. Moreover, the increase in extreme weather events due to climate change is regarded as one of the most critical factors that is likely to affect the supply of plant sources.

Infrastructure: Significant investment and planning are required for the construction of facilities for alternative protein production, such as fermentation technologies, cultivated meat technologies, and insect farming, which are currently being studied at the laboratory/pilot scale.

Legislation: Legal frameworks regarding safety assessment processes, toxicity testing, and labelling of new protein sources are expected to be drawn.

15. Plant-based protein sources (existing and new sources) with increased bioavailability show promise for the short and medium term. In the medium and long term, new sources (algae, insects, mycoproteins, etc.) are likely to enter the market, and the most robust alternative protein options for the long term are likely to come from the field of biotechnology (e.g. precision fermentation products). Again, in the long term, it is envisaged that cultured meat would only have a place if scalability problems are solved and costs are reduced.
16. The potential to use qualified wastes generated in food/agriculture and similar sectors as raw materials in the production processes of alternative proteins creates a significant opportunity for the development of circular bio-economies by contributing to waste management.
17. Today, the alternative protein sector is progressing in the form of a “technology push.” The demand side, or consumers, does not currently feel any necessity and is largely unaware of the latest developments. Governments, some investors, and a limited number of stakeholders in the technology ecosystem of some countries

are “keenly” interested in what technology can offer for the future. It should not be ignored that many options are still at the research and development stage.

18. The solutions for alternative proteins are not expected to be uniform. Each country, region, geography, and culture would have a differentiated strategy and road map.
19. In Türkiye, comprehensive discussions on alternative proteins have only recently started, and currently, no market/consumer research is conducted in this field.

2. Alternative Proteins: New Sources And New Technologies

The potential uses of these new sources and technologies within the framework of the existing animal food value chain are shown in Fig. 3:

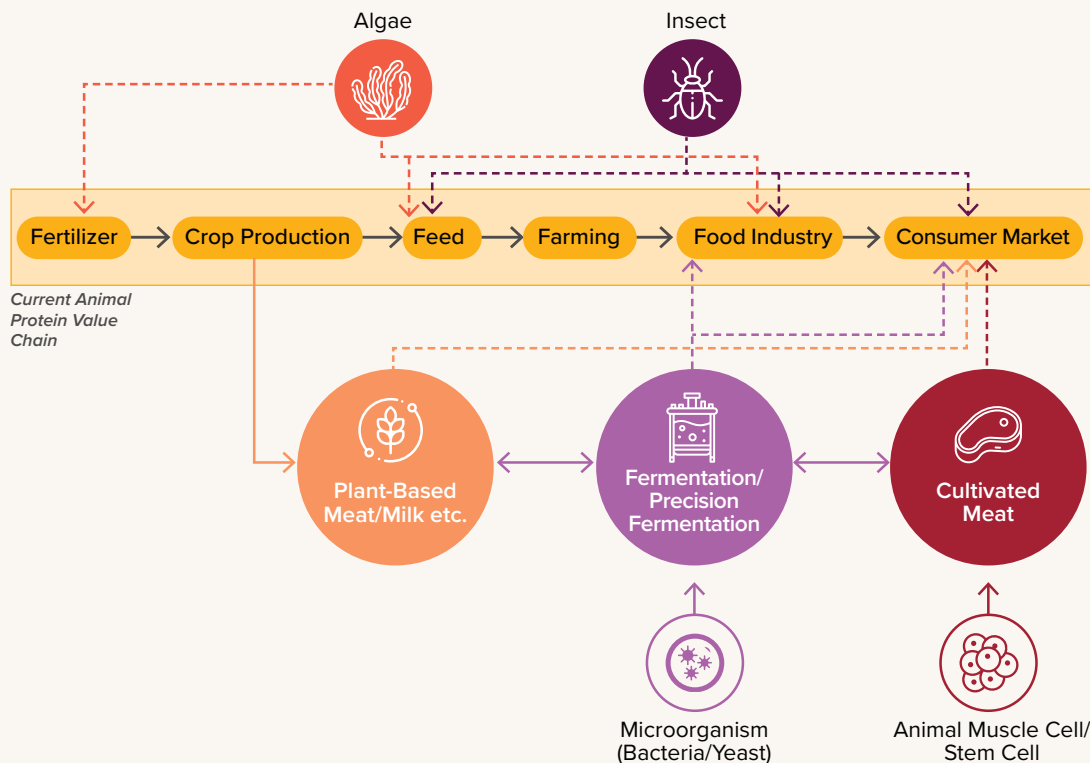


Fig. 3. Insights into the Potential Use of Alternative Proteins in the Current Food Value Chain

In the current animal food value chain, fertilizer, which is shown as the first step in agricultural production, is a basic input for crop production. Various outputs obtained from crop production are used as animal feed. Products obtained from animal husbandry (meat, milk, and eggs) are channeled into the food sector and packaged/processed/distributed to the consumer market (Various products from crop production, such as legumes and cereals, which are not clearly shown here because of the animal food value chain, are also sources of plant protein and provide inputs to the food sector for direct human consumption).

The colored dashed arrows show insights and possibilities of how alternative proteins could be integrated into the existing food chain. The arrows pointing to the “Food Industry” refer to food ingredients (protein concentrates/isolates, insect protein powder, spirulina/chlorella powder, etc.) obtained as a result of the alternative protein production process. On the other hand, the arrows pointing to the “Consumer Market” represent the ready-to-consume food product. In this figure, the double-sided arrows show that alternative protein products could be inputs for each other:

- It is stated that algae have the potential to be used both as fertilizers and directly as feed and food components.
- Insects, on the other side, have the potential to be used as an alternative source of feed (for poultry and seafood) and as an ingredient in pet food. The availability of insects as human food is controversial. It is suggested that they could be powdered and used as a food ingredient or as a whole human food product in markets where they have the potential to be accepted by the consumer.
- Plant-based meat, milk, and dairy products (and similar products) that are derived from plant-based proteins could be offered to the consumer market.
- Proteins obtained through fermentation/precision fermentation (mycoprotein, whey protein, etc.) could be used as food ingredients in food production of non-animal origin (in milk production of non-animal origin, as meat analog, etc.). Products such as tempeh obtained by traditional fermentation are already being consumed. Fermentation-based protein powders could also be introduced to various consumer markets.
- Unstructured products (minced meat, nuggets, etc.) or structured products (steaks, fillets) obtained as a result of cultivated meat production could be made available to end consumers.

Availability here refers to the technical possibility. The acceptance of a food product is associated with many different criteria. It should not be expected that every technology or resource would be accepted everywhere.

In alternative protein technologies, estimates of the market share that each product category is likely to have vary considerably. For example, one study forecasts that plant-based meat and cultivated meat will account for 35% and 25% of the total meat market by 2040, respectively [10]. Another forecast suggests that by 2035, new alternative meat categories could account for 16% (plant-based), 5% (fermented), and 1% (cultivated) of the total meat market, respectively, totaling 22% [11]. According to data compiled by the World Economic Forum, by 2035 the alternative protein market is expected to grow from 13 million metric tonnes per annum to 97 million metric tonnes, more than seven times its current size, and to account for 11% of the overall protein market (with regulatory support and technological developments, this share could reach 22%). Taking into account that alternative proteins would generate an average income of USD 3 per kilogram, this would indicate a market size of approximately USD 290 billion. Fig. 4 shows, for each protein source (plant-based, fermentation-based, cultivated meat), the consumption amounts (million metric tonnes) for the period between 2020 and 2035, and the compound annual growth rates (CAGR) between these periods. It is estimated that alternative protein consumption will grow in three waves. The fastest growth period for fermentation-based products is estimated to be between 2025 and 2030, and for cultivated meat between 2030 and 2035. Consumption of plant-based products is growing steadily [12]. It should not be ignored that these data are just forecasts.

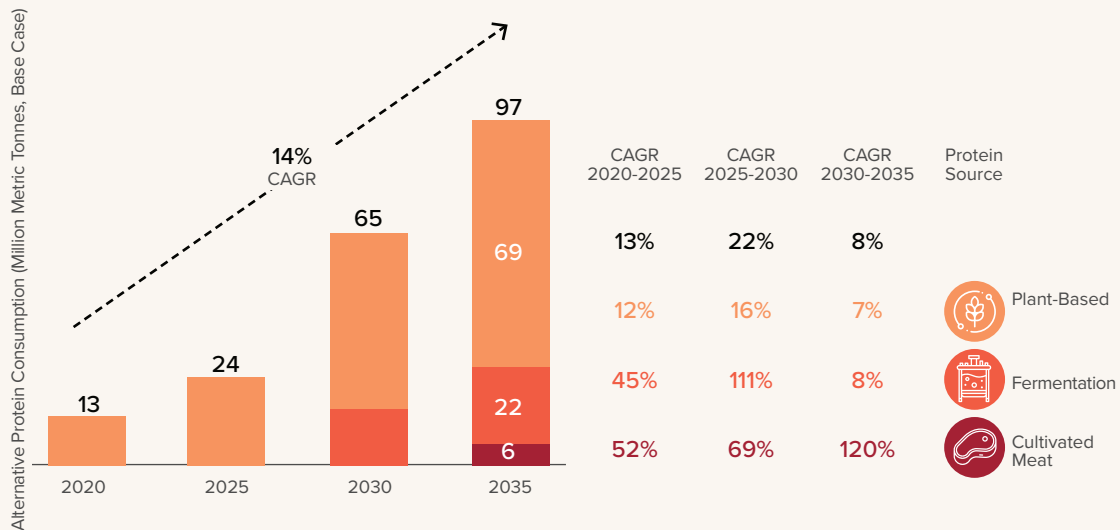


Fig. 4. Forecast of Alternative Protein Consumption and Compound Annual Growth Rates

The insect protein industry is also a growing sector, and the market is expected to reach USD 1,395.54 million by 2029 from USD 543.67 million in 2021, with a compound growth rate of 24.7% [13].

2.1 Plant-Based Protein Technologies

In the alternative protein industry, in addition to plant-based “meat” and “fish meat” products, plant-based alternatives to animal-based products such as “milk,” “yoghurt,” “cheese,” and “eggs” are also being developed. Although the product formulations and production processes of these alternative plant-based products differ from each other, proteins extracted from plant sources are the key ingredients for each of them.

The development process of plant-based products starts with the crop development step, continues with the processing of the plant raw material and protein extraction, and ends with the final product formulation, processing, and production step. In Fig. 5, the process of obtaining plant-based meat is outlined.

The most widely used plant source for plant-based products is soy. Soybean is followed by wheat, pea, and buckwheat, respectively. There are also various plant-based protein

sources with significant potential for growth (such as sunflower, chickpeas, oats, mung beans, cashew nuts, chia seeds, sesame seeds, fruit kernels, etc.). One of the key factors for these protein sources to compete effectively with soy and wheat is how efficiently they can be texturized. In order to increase volumes and reduce costs for these resources, scale-up and commercial development are required [14].

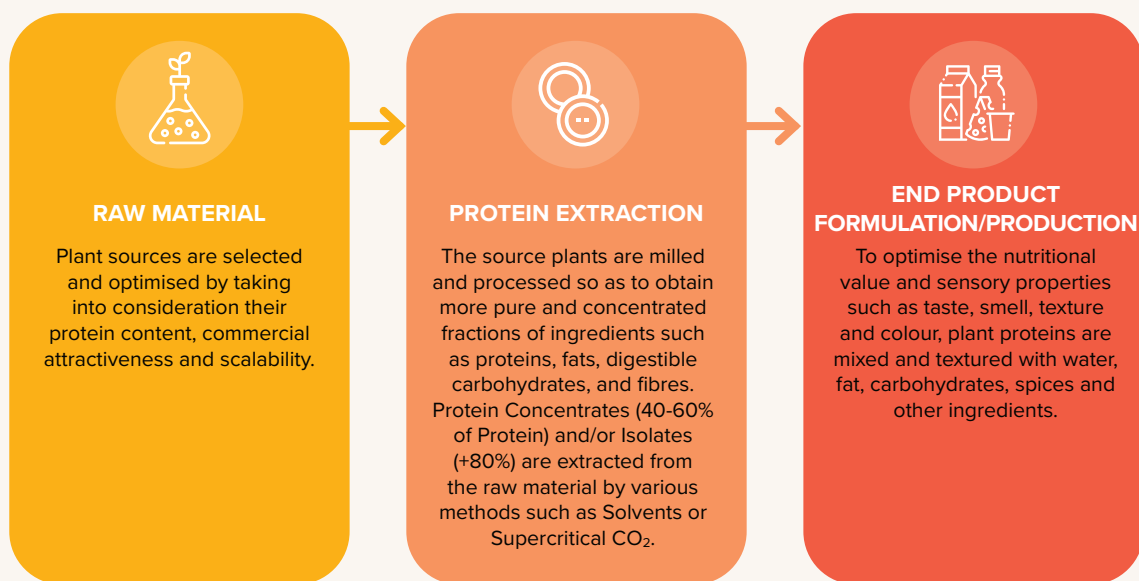


Fig. 5. Process of Obtaining Plant-Based Products [15]

The production of plant-based proteins dates back centuries. Classic products such as tofu, tempeh, and seitan have been consumed as alternatives to animal-based proteins due to their high protein content. The first plant-based burgers introduced in the 1960s-1970s were also designed to appeal specifically to vegetarian consumers and were not intended to mimic the sensory profile of conventional meat [16]. However, today's new generation of plant-based meat products is being developed by using new technological approaches aimed at mimicking the organoleptic properties of conventional meat, such as taste, smell, texture, and colour, down to the finest detail and presenting the meat experience more realistically [17]. Nowadays, plant-based meat options aim to appeal to the vegetarian/vegan group as well as the rapidly growing "flexitarian" consumer segment. The effort

to “liken” plant-based products to animal-based products brings with it some problems. Aromatic flavour enhancers and other synthetic additives added to plant-based products, as well as the processes applied to texturize them, place them in the category of “heavily processed and adulterated products” and raise health concerns due to their high sodium content.

The rough protein amounts of food products obtained from alternative plant-based proteins are known, but the types and amounts of amino acids contained in these foods and their rates of meeting amino acid needs are not known/determined. It is known that plant-based proteins lack some of the essential amino acids (e.g. soybeans are deficient in amino acids such as methionine and cysteine) and have lower bioavailability compared to animal proteins. At this point, the bioavailability of plant sources could be increased thanks to various techniques and technologies and the nutritional value of plant-based products could be improved by increasing the protein quality (DIAAS / PDCAAS Scores) through the combination (blending) of two or more different plant proteins. Plant sources may contain components that cause bad/bitter taste such as alkaloids, and some antinutritional factors such as trypsin inhibitors, phytic acid, and lectin, which can make digestion of proteins and absorption of some minerals & micronutrients difficult. This could be minimized by correct processing and cooking techniques [18].

One of the most important parameters in plant protein extraction is “Yield”. Questions such as how much of the plant source can be produced, how much protein can be extracted (scaling up), and what the processing costs will be are the most important factors while producing plant-based protein. Expansion of the production capacity that is needed to feed large populations on a global scale poses a significant challenge. For example, soya beans and peas are the main sources of plant-based protein today, but production volumes of both - for use in human food - remain inadequate. Especially soybean is currently mainly used as an ingredient in animal feed. Cultivating plant sources with better flavour and higher protein content could improve both product quality and scalability. In addition, it is necessary to find areas for the utilization of the excess by-products (starch, carbohydrates, fibre) after the extraction of proteins from plant sources [18, 19].

Plant-based proteins are the most advanced among today’s alternative proteins in terms of scale, availability, and acceptability. However, the costs of production are still about twice as high compared to conventional animal proteins. There is a need for intensive

innovation to diversify the product range of plant proteins, improve product ingredients, and reduce the price [19].

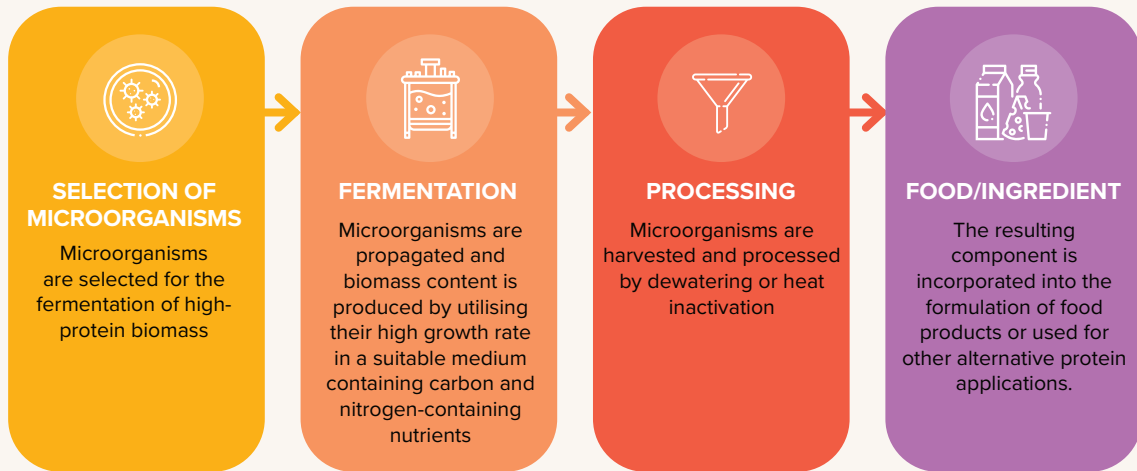
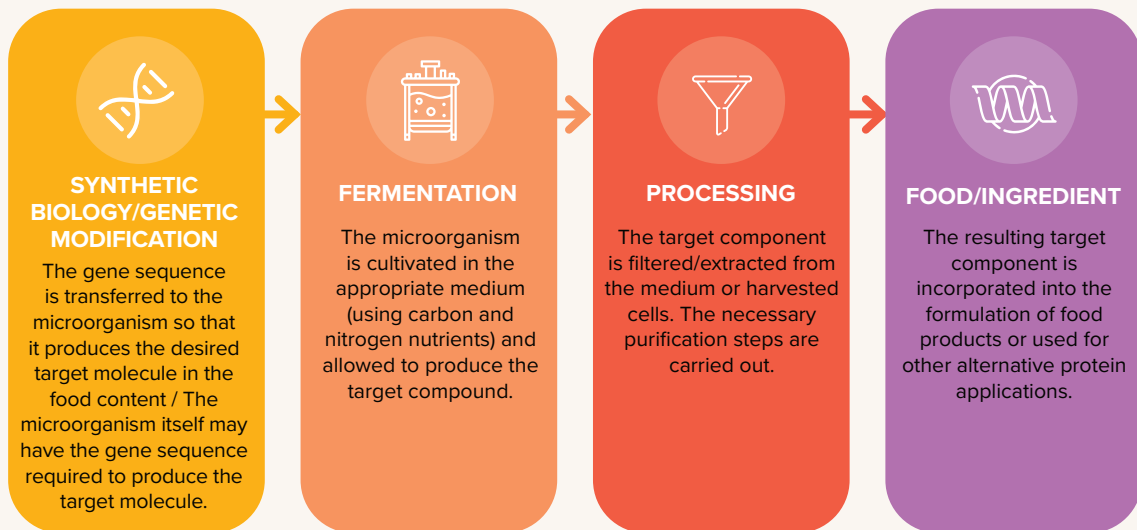
According to studies comparing the environmental impacts associated with plant-based products with those of conventional animal products, plant-based meat production has been shown to consume 30-50% less energy, require 86-97% less land use, and have 67-89% lower greenhouse gas emission values compared to that of beef meat [20, 21]. However, these values may vary according to parameters such as the source of energy used in the production process, the production process itself, and the type of conventional meat being compared. In addition, more data are needed to compare water use [9, 22].

2.2 Fermentation-Based Protein Technologies

Due to various reasons, such as the way of using microorganisms (bacteria, yeast, filamentous fungi, microalgae) and differences in the end product, fermentation technologies are divided into 3 categories: *traditional fermentation*, *biomass fermentation*, and *precision fermentation*. Although traditional fermentation is almost as old as known human history, thanks to the wide diversity of microorganisms and significant advances in synthetic biology, especially “biomass fermentation” and “precision fermentation” technologies have great potential to develop alternative or complementary products to animal products. Thus, they have attracted considerable interest in the alternative protein sector in recent years [23].

Through biomass fermentation, microorganisms isolated from pure microbial cultures are grown on a variety of carbon sources, resulting in dead and dried, protein-rich cell biomass. This obtained biomass is called “microbial protein” or “single cell protein” (SCP). In the precision fermentation process, specially designed microbial hosts are used for the production of target functional components such as milk proteins, egg proteins, collagen proteins, heme proteins, enzymes, and natural pigments [24].

In Fig. 6 and Fig. 7, alternative protein production processes by biomass fermentation and precision fermentation methods are outlined and simply illustrated:

**Fig. 6.** Biomass Fermentation Process [25]**Fig. 7.** Precision Fermentation Process [25]

Although studies on the metabolic design of microorganisms, raw material design, and improvement of bioprocess for more efficient production of fermentation-based proteins (more protein in less time with less input) are continuing rapidly, the biggest obstacle to the production of these proteins is expressed as “scaling”. Particularly with regard to precision fermentation, companies need more time to mature their technology and scale up their production profitably.

The potential of using alternative and low-cost raw materials/substrates (food waste, agricultural waste, domestic/industrial waste, etc.) in fermentation processes is of interest in terms of both reducing production costs and contributing to waste management. However, single-cell proteins (microbial proteins) obtained by biomass fermentation have potential safety concerns due to their high nucleic acid content and other toxicity issues.

It is thought that with advances in industrial technology, the development of downstream processes such as centrifugation, filtration, and drying can reduce the cost of liquid-solid separation, and this could have a considerable impact on product quality and scalability [19].

It is proven that fermentation-based proteins have a lower land use and water footprint than conventionally produced proteins. The potential reduction in greenhouse gas emissions they provide is largely dependent on the energy source used in their production, and significant gains are achieved as a result of the use of low-carbon energy [26, 27].

2.3 Cultivated Meat

Cultivated Meat is the name given to the end product obtained by developing and differentiating stem cells taken directly from the muscle tissues of animals by biopsy in a laboratory environment, by providing an animal-(fetal bovine serum [FBS]) or plant-based growth medium, in a temperature and humidity-controlled bioreactor, first into mature muscle cells and then into larger muscle tissues (Fig. 8) [28-30].

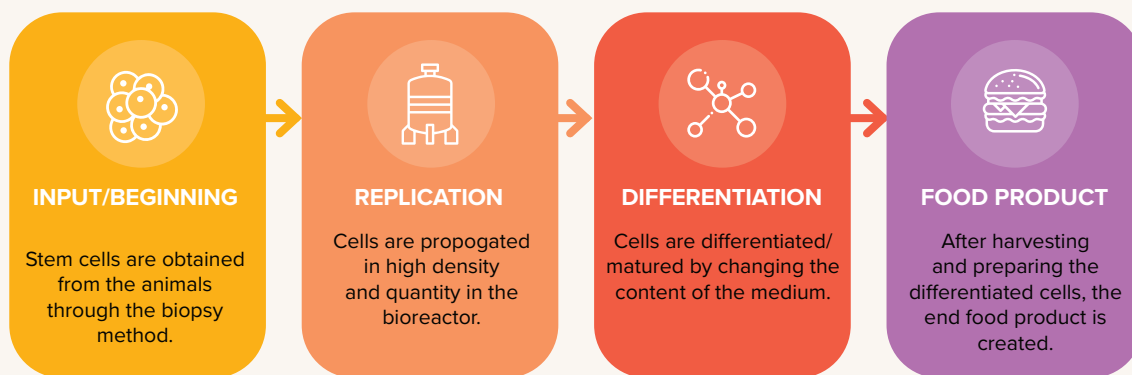


Fig. 8. Cultivated Meat Production Flow [31]

Cultivated meat production techniques are divided into two main categories: “Cell-Culture/Scaffold” based technique and “Self-organising/Tissue-Culture” based technique. Production techniques that are at an early development stage are 3D Printing, Biophotonics, and Nanotechnology. As a result of *in vitro* production, it is important that the cultivated meat contains the same sensory and nutritional properties as conventional meat. In addition to red meat, studies are also being carried out to produce chicken, pork, fish, or other seafood with cultivated meat technologies [32-34].

The production of cultivated meat is a very costly process, and the first cultivated meat hamburger in the world was produced in 2013 at a cost of USD 330,000. The cost of cultivated meat production is expected to fall to USD 500 per kg in 2025. The cost of the growth medium constitutes the majority of the costs. 80% of the cost of the growth medium comes from growth factors and 80% of that comes from albumin protein. The components currently used are generally “Research Grade” (high purity-high cost suitable for use in the laboratory) and it is estimated that the cost would decrease once they are “Food Grade” (extracts, natural products, food components). The development of plant-based growth mediums is in progress. In addition, it is currently not possible to co-culture the different types of tissues that make up the cultivated meat, such as muscle tissue and adipose tissue, since the growth media they require are different.

Cultivated meat is an early-stage technology with ongoing research and development studies. Although the regulations and legislations regarding cultivated meat vary, there is no development regarding the production and consumption of cultivated meat on a large scale

in Türkiye. Furthermore, it is not known how societies would react to cultivated meat due to religious or sociocultural reasons and how cultivated meat would affect human health.

Cultivated meat, compared to conventional red meat, is believed to have the potential to reduce greenhouse gas emissions, agricultural land use, air pollution, and marine eutrophication. The amount of energy used in the production of cultivated meat is characterized as having similar or higher values compared to conventional meat production [31, 35].

2.4 Extraction of Protein from Alternative Sources

Insect Protein

Insect Proteins, which are today consumed by nearly 2 billion people, attract attention due to their lower environmental impact and their potential to be used in different areas such as food products, feed, and cosmetics sector [13, 36].

The production procedures of insect protein from which insect oil and fatty/non-fatty insect protein powders can be obtained are shown in Fig.9.

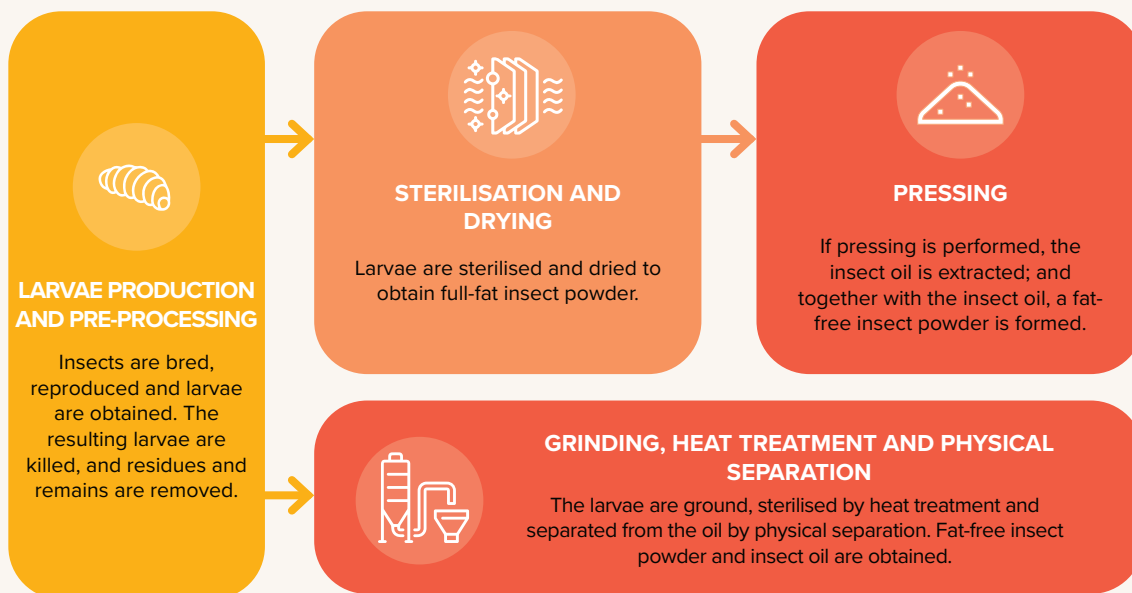


Fig. 9. Insect Protein Production Flow [37-39]

According to studies, insect production has been shown to have lower greenhouse gas and ammonia emissions compared to cattle husbandry. Insect production requires much less water and feed inputs and less land area [40, 41]. Insects possess the capability to convert nutrient-rich waste, such as food waste, into protein. Because of these reasons, insect proteins are expected to become one of the solutions for the transition to sustainable food systems.

Despite all these advantages, the widespread use of insects as human food is hampered by cultural acceptance difficulties. Although there are various product market tests, insect proteins are not yet among the leading technologies, even in the Asian market, which is expected to be more widespread and dominant. Insect proteins could be considered to be a source of quality protein as a feed and pet food ingredient in poultry and seafood farming instead of being an ingredient for human food.

Currently, legislative regulations and developments regarding the use of insects in human nutrition and as animal feed are ongoing globally. In Europe, certain types of insects are recognized for human consumption. The use of feeds/foods produced from insects in poultry, pet, and seafood farming is also recognized.

Algae Protein

Algae are generally classified as macroalgae (eukaryotic) and microalgae (prokaryotic) according to their size. Macroalgae and microalgae differ in structure as well as in size. For instance, macroalgae have a higher sugar content, while microalgae have a higher protein content [42].

Microalgae possess the capability to convert micromolecules such as carbon dioxide or ammonium into valuable macromolecules such as proteins. Microalgae exhibit high growth rate and photosynthetic efficiency, resulting in high protein (60-70% of dry weight) and lipid contents. Although many microalgae species are included in the Generally Recognised as Safe (GRAS) classification by the US Food and Drug Administration (FDA), their use as food and feed requires caution due to their potential toxicity and their high nucleic acid content (up to 6%) [42, 43]. Microalgae proteins are discussed in this report under the title of “Extraction of Fermentation-Based Proteins”.

Macroalgae, which are also known as seaweeds, are a distinct group of multicellular, fast-

growing, large-sized, plant-like Protista visible to the naked eye. While seaweeds are vital for marine ecosystems and for CO₂ capture, they also play an increasingly important role in the production of biofuels, the pharmaceutical industry, and animal and human nutrition. Algae are rich in protein and bioactive compounds that are beneficial for the healthy development of fish, making them particularly important for aquaculture. Global production of macroalgae is mainly centred in Asia [44]. Increasing macroalgae production to meet market demand is a challenge for the sector. A comprehensive assessment of the food safety risks of macroalgae is needed. In addition, long-term data on the environmental impacts of macroalgae cultivation at an industrial scale are still lacking. It is important to balance the potential benefits of production with environmental risks and to ensure that the carrying capacity of receiving environments is not exceeded [45].

Mycoprotein

Mycoproteins are obtained by biomass fermentation using filamentous fungal species and are often used as meat analogues in plant-based meat production. For the first time, a company titled Quorn developed a protein-rich meat-like product using a filamentous fungus, *Fusarium Venenatum*. Nowadays, some product prototypes are also being developed, such as mycoprotein-based squid, mycelium-based pork, chicken fillets, and foie gras. Quorn calculated the PDCAAS value of their mycoprotein to be 96-97%, showing that it exhibits a protein quality equivalent to high-quality protein such as egg and cow's milk, and even with a higher score than soya and beef [46].

Although there are a limited number of studies on the allergenic potential of mycoproteins, studies suggest that reactions usually occur when people are first exposed to mycoprotein-based food products, particularly in people who are sensitive to inhaling mold allergens. [45]. Mycoproteins are discussed in this report under the title of "Fermentation-Based Proteins".

Jellyfish Protein

Today, jellyfish sourced from capture fisheries have a significant market in Asia [47]. Even today, while many new techniques are available, the cultivation of most species of jellyfish is a challenging task and studies in this area are still ongoing [48]. The lack of national safety and quality standards for the consumption of edible jellyfish is one of the barriers to its dissemination and the development of the sector [45]. This resource, which is abundant in the waters of our country, but not yet being fished, could enable the creation of a sustainable and innovative

economic activity area by applying different processing methods [49]. However, requirements are needed for large-scale supply, such as the development of cultivation methods and the establishment of standards.

2.5 Interactions of Technologies

Although the product outputs of technologies categorized as plant-based, fermentation-based, and cultivated meat, which are offered as alternatives to traditional animal-based foods, have different characteristics, they are not independent of each other. The outputs obtained from each of them may have applicable areas to be used in another technology. Fig. 10 illustrates an example of this situation. With the merging of different technologies, it is anticipated that there will be consolidation among alternative protein companies over time, and more end products covering all three technologies are likely to be brought to market [50]. For example, it is considered that the use of cell-based fat, which is said to be less costly than the development of cultivated meat, in plant-based meat products has the potential to better meet the flavour expectations of consumers.

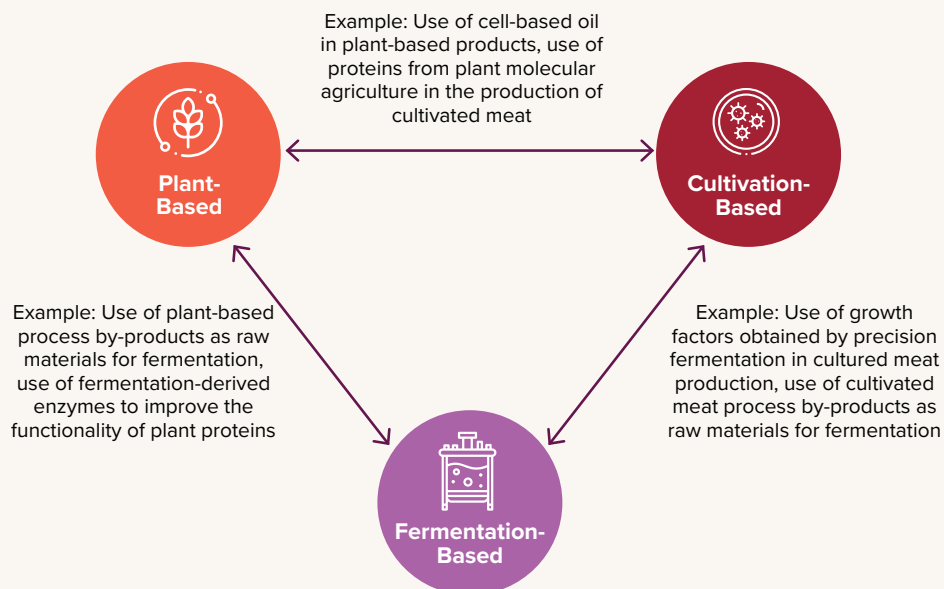


Fig. 10. Interaction between Alternative Protein Technologies

Moreover, it is thought that combining plant-based meat with small amounts of cultivated meat may allow the development of products that are more cost-effective than cultivated meat on its own and have sensory characteristics more similar to conventional meat. There is even a point of view that the inclusion of small amounts of conventional animal meat in such hybrid products could significantly increase product appeal [9, 20].

3. Investments In Alternative Protein Technologies

Companies engaged in alternative protein businesses attracted a total investment of USD 14.2 billion between 2010 and 2022. During this period, although there have been large fluctuations on an annual basis, companies have shown remarkable growth, with investments almost doubling every year on average [51]. However, this rapid increase slowed down in 2022. It could be argued that the reduced funding for alternative proteins is a reflection of the global slowdown in investment, overall in many sectors. Fig. 11 shows the investments made in each region. It is noteworthy that in 2022, alternative protein investments in the European Union (EU) increased by approximately 91% , while worldwide alternative protein investments declined by 42%.

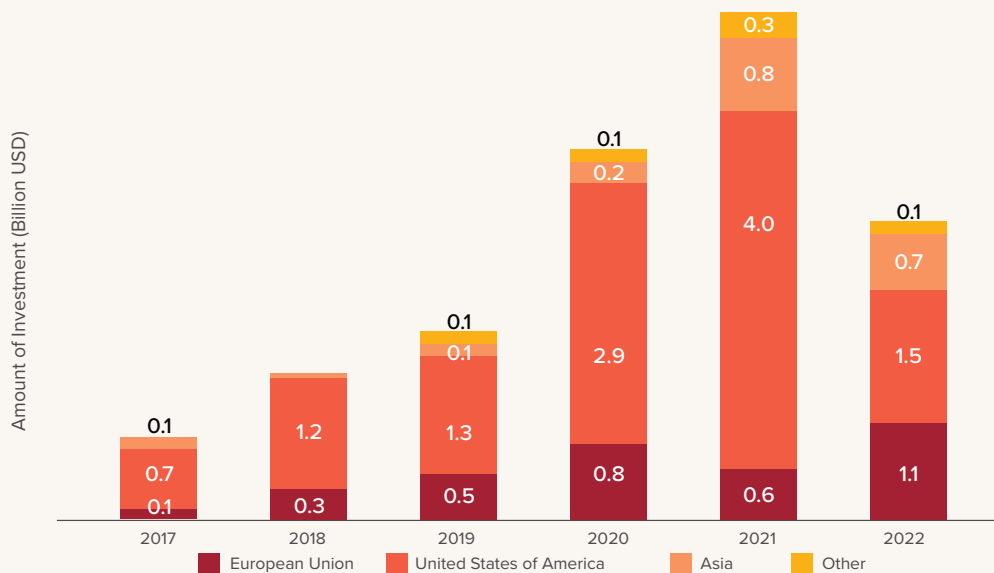


Fig. 11. Amount of Investments in Alternative Protein Technologies by Region and Year [52]

The alternative protein sector is an investment-intensive field. During the period when financial resources were abundant and costs were cheap, large investments were made in the alternative protein industry in the USA; however, high-tech and radical innovation in the food sector is not progressing rapidly. It takes a long time for the studies to be finalized, and there is a need for continuity in the flow of financial resources during this period. It is reported that investors with experience in other sectors, particularly software, are disappointed, and private investments are decreasing due to expectations of quick returns and high opportunity costs. It is also highlighted that there is a need for government support in order to ensure investments for longer years.

4. Recommendations for Türkiye

Considering climate change and its potential impacts, Türkiye needs to increase its efforts to obtain protein from sustainable sources in the future. If we simplify the problem, the question “Are we going to have access to milk, meat, egg, legumes, and even food overall in the future?” is becoming increasingly important.

While searching for answers to this question, countries are developing alternative protein-based strategies and road maps, and conducting technological studies on the subject. Despite the extensive and rapid developments in the field of alternative proteins, the approach to protein in our country is mostly discussed and progressed within the framework of traditional practices such as animal husbandry, stockbreeding, and breeding.

- Even today, there are still issues that need to be dealt with within our country:
 - Despite the variety of products that can be produced, it is considered that there are protein deficiencies in nutrition, especially in children.
 - The proportion of imported products in food, feed, and even fertilizer components is quite large. Various basic materials or qualified components are imported. This poses a major risk in terms of food safety.
 - Alternative Protein Technologies have the potential to contribute to overcoming such protein deficiencies and mitigating food security risks.

- It is also important to recognize that the food transformation that is taking place is not only a “threat” but also an opportunity. Our country has considerable advantages in this field:
 - Different climate regimes are experienced (and even microclimates coexist),
 - Soil characteristics change over short distances,
 - It has a large, versatile, and diverse culinary culture based on a wide variety of sources with a considerable amount of plant resources,
 - Logistic advantages of our country in terms of its geographical location.

All of these show that beyond meeting its own needs, thanks to the product diversity it can create in the future, alternative proteins could play a major role globally, especially in the near geography, from resources to the kitchen. Although there are some products that cannot be consumed domestically, it is important to work on innovative technologies for export purposes in terms of development and improvement.

While on the one hand, climate change has started showing its impacts, on the other hand, there is a risk that it may be too late to develop a strategy once technologies develop and transformation is at the doorstep. For this, future scenarios need to be created; data and evidence-based food strategies, and accordingly, a protein strategy and roadmap need to be developed. In addition, legislation on Novel Foods is recommended to be published in a country-specific manner.

For our country, we consider alternative proteins primarily as a supplement to traditional animal products such as meat and milk. We anticipate that demand for animal-based proteins will continue and that every protein source will have a place to a greater or lesser extent in the future (both traditional and alternative). In this context, in line with global trends, it is foreseen that cattle breeding (both meat and milk) has the potential to decrease, while small cattle breeding may increase in some places, with poultry farming, especially chicken, increasing. It is also predicted that mass seafood fisheries will decrease while farmed seafood will increase. We believe that the alternative protein industry should be further developed in the short and medium term, not to compete with the traditional animal product market, but as a food supply security instrument in order to increase product diversity, provide food for more people, improve the low-protein dietary profile, establish a fair and sustainable food system and ensure the sustainability of food supply in the event of a disaster.

For these reasons, it is important to carry out studies on additional protein sources that would support the growth of sustainable bio-economy in our country. Türkiye needs to identify focus areas for alternative protein technologies and industrial opportunities for each of these areas. Investment priorities should be identified for each focus area.

Globally, in the medium and long term, scenarios converging to a flexitarian diet are becoming more likely to be recognized. However, each country, region, geography, and culture will have a different story. Therefore, each society must prepare its own strategy and road map.

Interestingly, it should not be ignored that the existing deep-rooted and rich cuisine of our country has a high weight of plant foods and, when meat consumption statistics are evaluated, it has an almost flexitarian character. This makes it possible to supply/export not only the raw materials of the products but also the culinary culture.

In the field of alternative proteins, the research and investment areas that offer potential opportunities for Türkiye can be listed as follows:

1. Türkiye is a country rich in plant-based protein sources (especially legumes and grains). The world is trying to move towards protein sources that are grown in the field (plant) rather than in the barn (animal) due to their impact on the climate and the environment. In order for Türkiye to reduce its dependence on foreign sources of plant-based protein and to reduce its transport-related emissions, it is recommended to pay importance to obtain protein from sources such as peas, chickpeas, lentils, beans, and cereals, which are considered to be strong sources of plant-based protein, and to obtain high quality and therefore high value-added plant-based protein sources by working on techniques and technologies aimed at increasing the “bioavailability” of existing plant-based sources. In addition to the existing plant sources (legumes and grains), qualified wastes of the agricultural/food industry, and species specific to our country/region or that could be produced efficiently and on a large scale in our country, etc. should be considered. Not only protein, but also various food components such as starch, fibre, etc. are critical for a complete meal product.
2. Türkiye has an estimated number of 11,000 plant species in total, while the total number of species in Europe is 11,500 [53]. Studies should be carried out to utilize Türkiye’s traditional plant protein sources and endemic/local plant species (lupin bean, gökçe

chickpea, black chickpea, and similar) more efficiently. Plant species with commercial potential should also be investigated for protein extraction, and studies should be carried out to determine and increase their bioavailability.

3. Studies should be carried out to examine the impacts of a new protein source on people's health. Its side effects such as allergy and disease-causing potential, should also be studied. The nutrient content and bioavailability of the potential species, i.e., the extent to which the food is suitable for human consumption and how efficiently it can be absorbed, processed, and utilized by the body, should be assessed. Following the investigation of the health risks in detail, the production method should be determined by investigating the physical and functional properties. In particular, it is recommended to develop systematics for in vitro and in vivo testing of new foods, to establish accredited testing centers and to support studies in this field.
4. In our country, significant amounts of qualified waste are produced by the food industry (in some cases, retail chain markets). At present, very little waste is utilized and some waste is best "as is" used as animal feed. Therefore, it is important to identify existing food by-products/wastes as plant protein sources, to evaluate their utilization, and to reintroduce them into the food chain (as human food or animal feed components) (those with high essential amino acid content should be identified). It should also be aimed at increasing the functional properties and bioavailability of proteins found in plant wastes by processing them with appropriate techniques. Priority should be given especially to the wastes obtained from plant sources produced and processed in our country (tomato pulp, pulses, sunflower pulp, hazelnut pulp, cottonseed, pomegranate seed, sesame shell, sour cherry seed, malt pulp, etc.) and traceability of these wastes should be ensured. In addition, it is necessary to establish a logistics system, market and price standards in a way to prevent the deterioration of these wastes. In order to realize the potential of quality waste produced on a regular basis and on a large scale:
 - a. It is important to identify wastes and conduct studies on waste management/ logistics/storage (including microbiological and toxicological aspects).
 - b. The development of a cataloging system for the inventory and composition of plant varieties containing protein and other food components, especially cereals and legumes, is important.

5. It is essential to approach all sources with the principles of a “circular economy”. For example: Studies that contribute to the circular bio-economy, such as obtaining products such as oil and flour from the pulp remaining after the use of plant sources such as hazelnuts and almonds in the production of plant-based milk and dairy products, and converting the shells into high-value products such as biochar and activated carbon should be encouraged.
6. It is crucial to carry out breeding studies in order to optimize crops in terms of protein content, quality, and function and to render them resistant to changing climatic conditions (such biotechnological work is necessary to ensure future food security).
7. In Türkiye, there is no industrial-scale facility for protein extraction/processing/ formulation processes; therefore, plant-based protein concentrates/isolates are imported. There is a need for technology and process development studies for protein extraction. For the future, it is recommended to support investments in facilities that produce isolated protein (from plant, animal and alternative sources).
8. For medium and long-term targets, studies on innovative resources and technologies should be increased and continued. Since fermentation technologies promise significant potential in this regard, technologies such as biomass fermentation and precision fermentation need to be developed. In addition, the establishment of a bioreactor industry by developing, designing, and producing innovative bioreactors/ fermenters would create a significant opportunity arm for our country. It is necessary to invest in pilot-scale food-grade fermentation plants, and in downstream process equipment intended for separation and purification.
9. Türkiye has an advantageous position for algae production since it is a country that receives intense sunlight. Studies should be carried out for the production of high-value algae protein, the production of algae-based feed ingredients, and the development of microalgae-based healthy snack products that would replace a meal. By capturing CO₂, which is used as a carbon source in algae production, from air and/ or point sources, it is possible to provide benefits to the field of “carbon capture and utilization” and to produce carbon-negative solutions.
10. With regard to insect proteins, they should be used primarily as an ingredient in

aquaculture, poultry feed, and pet food, thus reducing the amount of imported feed raw materials and quality food. In this context, it is necessary to examine insect breeding and technologies, to support research on the nutritional profile of insects, and to develop legal and regulatory processes to define the use of insects as feed.

- 11 Cultivated meat is currently not permitted to be consumed in Türkiye. However, conducting biotechnological studies in the field of cultivated meat is important for developments in sectors other than food (e.g., artificial organs and tissues). Additionally, it will be of value in terms of expanding our export capacity and building our know-how in our country.
12. Although the food-processing sector is highly developed in our country, it is not possible to say the same for the fields of biotechnology and industrial microbiology. There is a need to make a special effort and support investments for the development of this field, which encompasses many critical sectors such as agriculture, veterinary, food, pharmaceutical, medicine, chemistry, etc.
13. In light of the foregoing, various research topics proposed to be supported in the field of R&D and Technology are as follows:
 - a. Investigation of native/local/endemic species (plants - e.g. lupin bean, local chickpea species, insects, fungi, etc.), their nutritional values (protein and essential amino acid contents, bio-utility analyses, production techniques, etc.) and their bioavailability/effects on the human body,
 - b. Researching the nutritional elements of innovative resources and carrying out studies to increase their bioavailability,
 - c. Development of bioavailability analyses and testing methodologies, and bioavailability simulators for new sources of food,
 - d. Production of drought-resistant and high protein quality legumes,
 - e. Development of fermentation technologies (targeted and biomass fermentation),
 - f. Establishment of the nutrition-food research center(s) - centers to research not only how food is processed but also to study its relationship with human welfare (physiological, psychological, health, etc.) and social welfare,
 - g. Performing life cycle analysis calculations by developing methodologies to assess the carbon emission and environmental impacts of food,

- h. Conducting research on consumer perception and consumer acceptance of alternative proteins,
- i. Development of studies in the field of biotechnology and industrial microbiology in general: microorganism (strain) development, design, and optimization.

In this context, in the field of alternative protein, it is of great importance to increase the research capacities of universities, encourage cooperation with the private sector, develop innovative food/biotechnology accelerator programmes, support the entrepreneurship ecosystem, and, most importantly, train qualified human resources.

5. Conclusion

Within the framework of the data obtained, it is thought that alternative proteins have the potential to be a supplement rather than a substitute or alternative to animal protein sources in the current food and nutrition value chain. In addition, alternative proteins could also play a quantitatively supplementary role in situations/periods where animal proteins are insufficient or their supply is interrupted. In summary, in most cases, it would be more appropriate to call them supplementary proteins rather than alternative proteins. The possibilities, at least in the short and medium term, are in favor of creating options rather than completely substituting animal sources, which is also an element of food supply security. Although it is estimated that every protein source would be more or less present in the future, it is not evident which protein source would be present in which geography/culture and to what extent. It should be taken into consideration that the estimations made for the 2050s and beyond consist of assumptions with very high deviations. Therefore, it is necessary to continue further research without excluding any new resources or technologies to utilize their results in due course.

To solve the scaling problem, which is seen as the biggest bottleneck in the production of alternative proteins, alternative protein producers need to perceive the market as profitable and reliable. At this juncture, governments are expected to provide research funding for alternative proteins, offer commercialization funding, and develop appropriate regulatory and legal frameworks. It seems that there is a correlation between successful alternative protein markets and direct public investment.

It is believed that the integration of alternative proteins into a country's food and agriculture sector can alleviate environmental, economic, health, and ethical concerns and contribute to the creation of a more sustainable and resilient food system. While the process of integrating alternative proteins into regulations is just beginning in Türkiye, the process of developing and changing regulations has accelerated worldwide. If the New Food Regulation, which is currently being worked on in Türkiye, is adopted, it is expected to encourage innovation in the food sector, enable the introduction of innovative food products to the market, and make progress on alternative proteins in this context. Furthermore, there is a need for market research on alternative proteins in our country in order to enhance progress on alternative proteins.

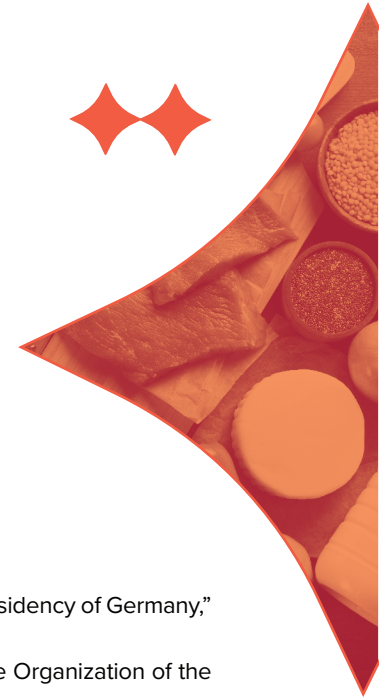
A table evaluating Türkiye's current approach to alternative protein technologies and new sources and their positioning in the market is presented below:

Table 1. Assessment of Alternative Protein Technologies and New Resources in Türkiye

		Food		Feed/Feed Additive
		Domestic Market	Foreign Market	
Technologies	Plant-Based Protein	✓	✓	✓
	Biomass Fermentation	✓	✓	✓
	Precision Fermentation	✓	✓	—
	Cultivated Meat	✗	✓	—
New Sources	Algae	✓	✓	✓
	Fungi (Mycelium)	✓	✓	✓
	Insect	✗	✓	✓
	New Plants (non-GMO)	✓	✓	✓

With Türkiye becoming a party to the Paris Convention, it is of utmost importance to evaluate these alternative protein production technologies, which have not yet been reflected in strategic and development plans, in order to make the national food system more environmentally friendly, sustainable, and healthy, and to maintain food security in line

with the goal of achieving the net zero target. Upon reviewing the Eleventh Development Plan of Türkiye, it has been observed that “protein” and “alternative protein” terms have not been emphasized in sections such as “Climate Changes, Food Security, and Effective Use of Water” where food issues are normally addressed. After a comprehensive and evidence-based definition of the protein problem is made, Türkiye is expected to prepare a roadmap on how to integrate alternative proteins into its existing food system, national targets, and strategic plans.



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PIONEER PROJECT PROGRAM ALTERNATIVE PROTEIN TECHNOLOGIES

DEEP DIVE STUDY - **SUMMARY**



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